EVALUATION OF THERMAL PROPERTIES AND LOG MOTIFS OF WELLS IN CENTRAL MALAY BASIN

By

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Project Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Technology (Hons)

(Petroleum Geosciences)

MAY 2014

Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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15129

A project dissertation submitted to the

Petroleum Geosciences Programme

Universiti Teknologi PETRONAS

in partial fulfilment of the requirement for the

BACHELOR OF TECHNOLOGY (Hons)

Approved by,

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TRONOH, PERAK

May 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

SITI HAJAR BINTI ZAMRIDIN

ACKNOWLEDGEMENT

First and foremost, praise to God for all His guidance and blessings for the accomplishment of this Final Year Project and to whom I owe my very existence. This would not have been possible without the support of many people. I would like to express my deepest appreciation to all those who provided me the possibility to complete this project. Also, I would like to express my gratitude towards my parents for their endless love, support and motivation through all my ups and downs.

A special gratitude I give to my respected supervisor, A.P. Wan Ismail Wan Yusoff, whose contribution in stimulating suggestions and encouragement, helped me to coordinate my project especially in writing this report. The cooperation of the co-supervisor, Mr. Abdull Halim B Abdul in completing the project is really appreciated.

I would like to express my special gratitude and thanks to all colleagues in Petroleum Geosciences pioneer batch who had been very helpful in providing me with endless encouragements and assistance. Special thanks go to Sofea Amiera Abdul Rahim, Nor Aqilah Mohd Anuar, Nur 'Izzati Bin Baba for the lovely friendship and support. Thank you everyone and may God bless us all.

ABSTRACT

Malay Basin is a result of complex tectonic mechanism shaped by 3 major tectonic events that give rise to the current structure in the basin; 1) **Extension** during Late Cretaceous to Early Miocene, 2) **Thermal subsidence** during Early Miocene to Middle Miocene and 3) **Compression** during Late Miocene to Pliocene. The targeted formations of this study are S, J and T fields. Pinnacle of this study in revolving around the petrophysical information and reservoir characterization with added minor study on Kelantan Delta environment could be a potential information through the comparison of the modern environment and historical environment of Malay Basin.

Interpretation of gamma ray, field mapping, geological experiment, profiling data of various variables corresponding to the thermal conductivity such as porosity, volume of shale and temperature is calibrated with the well log to find the empirical relationship between thermal conductivity and depositional environment which will be conducted in an attempt to better understand the unfolded story of the specific petrophysical data of Malay Basin with comparison to the modern environment of Kelantan Delta. Extended period of time, methods of better accuracy and more extensive study are recommended for future works in enhancing the understanding and knowledge about the reservoir characterization of several fields in Malay Basin mainly.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Petroleum exploration in the Malay Basin began in 1968 and now in a relatively mature stage. Data collected by the petroleum industry over the years have resulted in numerous studies that have helped improve the understanding of the petroleum basin system. Abrupt changes in gamma-ray logs response are commonly related to sharp lithological breaks associated with unconformities and sequence boundaries (Krassay 1998). Integrated analysis of well log can be very useful in identifying the major chronological histories of the stratigraphic area, interpret the depositional environment as well as the evaluation of the formation characteristics. Reservoir characteristics; thermodynamics and pressure behavior of the reservoir is very significant in analyzing further well developments to prevent any negative effects such as blow out and formation damage.

1.2 Problem Statement

Subsurface facies analysis gamma ray tool is the most useful due to its characteristic response to different lithologies (Posamentier and Allen, 1998). Different rocks emit differing amount of gamma radiation, normally by decay of potassium, thorium and uranium compounds and these values, which are recorded by the gamma ray logging tool can be used as a proxy to determine the lithology of the formation. In addition, many of the sand-rich facies also have distinctive gamma-ray signature. Therefore, an assessment of the thermal properties is carried out with respect to the deposition of environment in Central Malay Basin in order to evaluate the impact of thermal characteristics with facies distributions.

1.3 Objectives

The objectives of this study include, but not limited to the:

1. Definition of the thermal properties of Central Malay Basin.
2. Determination of variables that influenced variation of thermal conductivity on rock properties
3. Justification of oil and gas reservoirs accumulation with relation to facies, thermal property, porosity and temperature

1.4 Relevancy of the project

Malay Basin has a complete record of Pre- Tertiary deposition of sedimentation history. Since Malay Basin contains crucial geophysical information, the logs can be reinterpreted based upon this parameters to produce more lithological interpretation to gain additional information on the incomplete and ambiguous lithological descriptions as well as to compare the results with the nearest well. Besides, this analysis can be used to review the analogue of other geological analysis in the nearby coastal plain area in terms of the depositional environment with respect to the porosity and other variables related.

1.5 Feasibility of the project

This project is feasible enough in terms of time and cost because the data about the particular area that is going to be analyzed have been provided. This project is expected to finish if working intensively within 3-4 months.

CHAPTER 2

LITERATURE REVIEW

2.1 Critical Literature Review

Geological background of Malay Basin

Malay Basin, an intracratonic basin, is a northwest trending elongate basin located in the north-eastern part of peninsular Malaysia about 500 km long and 200 km wide. It is composed of complex half grabens structure that filled with sediments up to 14 km that are Oligocene to recent in age (Abd Rahim Md Arshad et al., 1995). The Oligocene sediments were generally terrestrial deposits with minor marine influence while the Miocene to recent sediment is coastal plain to shallow marine deposits.

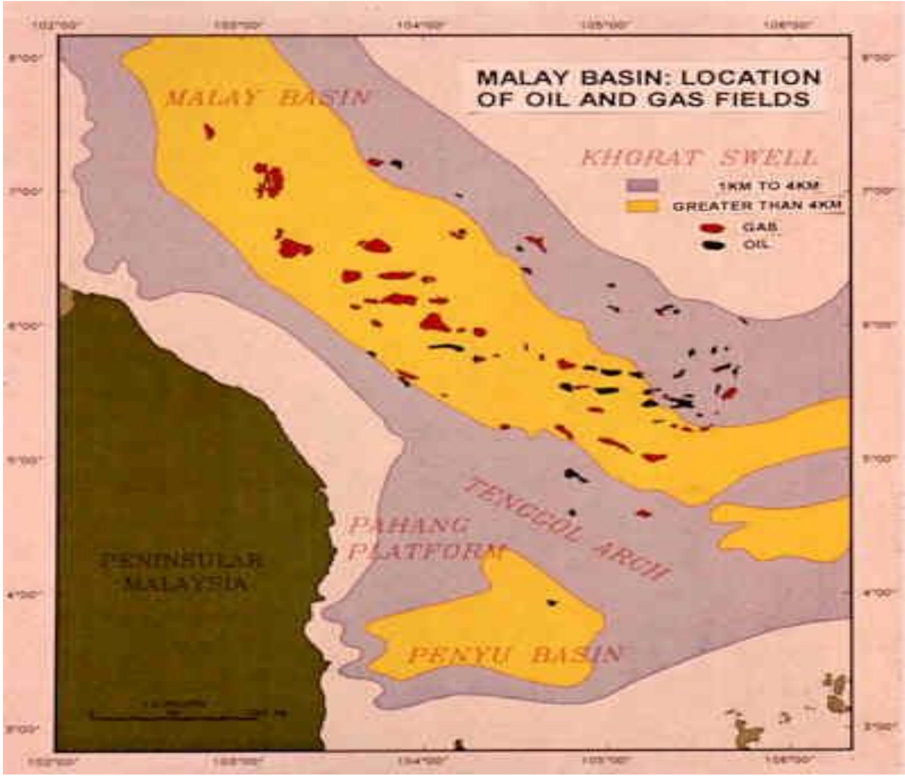


Figure 1: Map location of Malay Basin and its oil and gas field location

Petroleum exploration in the Malay Basin began in 1998 and is now in a relatively mature stage. Many oil and gas accumulation have been discovered since 1960s.

Most of the sedimentary section of the Malay Basin is composed of siliciclastic sequences of sandstone and shale. The alternating sandstone-shale sequences give good acoustic impendence seismic markers reading that were used to construct the stratigraphy for Malay Basin. One of the well-known stratigraphic correlations was established by Esso in the late 1960 and the sedimentary succession was subdivided alphabetically into units called “Groups” (Petronas, 1999). It was labeled from Group A to Group M from younger to older strata. These sediments are mostly lacustrine shales, coal and continental siliciclastics (Mohd Tahir Ismail et. al,1994)

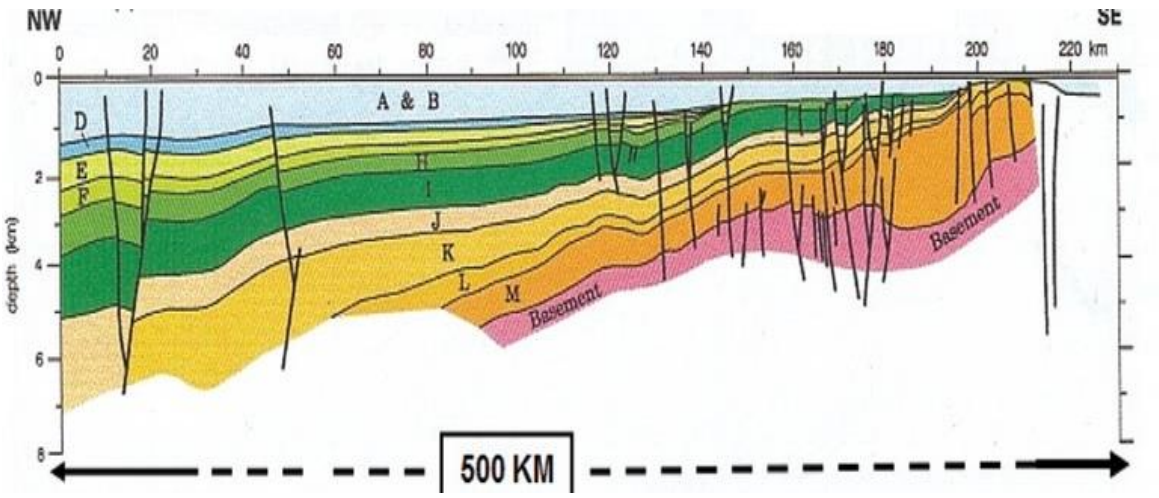


Figure 2: Stratigraphic map showing the overall geometry and structural styles

The basin has undergone three major tectonic events that give rise to the current structure in the basin; 1) **Extension** during Late Cretaceous to Early Miocene, 2) **Thermal subsidence** during Early Miocene to Middle Miocene and 3) **Compression** during Late Miocene to Pliocene. Half grabens structure across the basin area was formed by the extension during Late Cretaceous to Early Miocene. Fluvio-deltaic and lacustrine sediment from Group M, L and K that are Oligocene to Miocene in age are recognized as the source rock for the petroleum system in this basin.

The main reservoir zone is in the Group K to Group D sediments that are mostly from fluvial origin was deposited during the thermal subsidence event that occurs during Lower Miocene to Middle Miocene. The compression that occur during middle Miocene to Pliocene reactivated the normal fault along the half grabens structure and gave rise to domal anticlinal features, which is the main type of hydrocarbon trap in Malay Basin. The widespread regional shale that occurs in Malay Basin reacts as the seal rock. All these petroleum system elements are well-preserved and are correctly placed in time and space in the Malay Basin and provide a suitable condition for hydrocarbon accumulation and production.

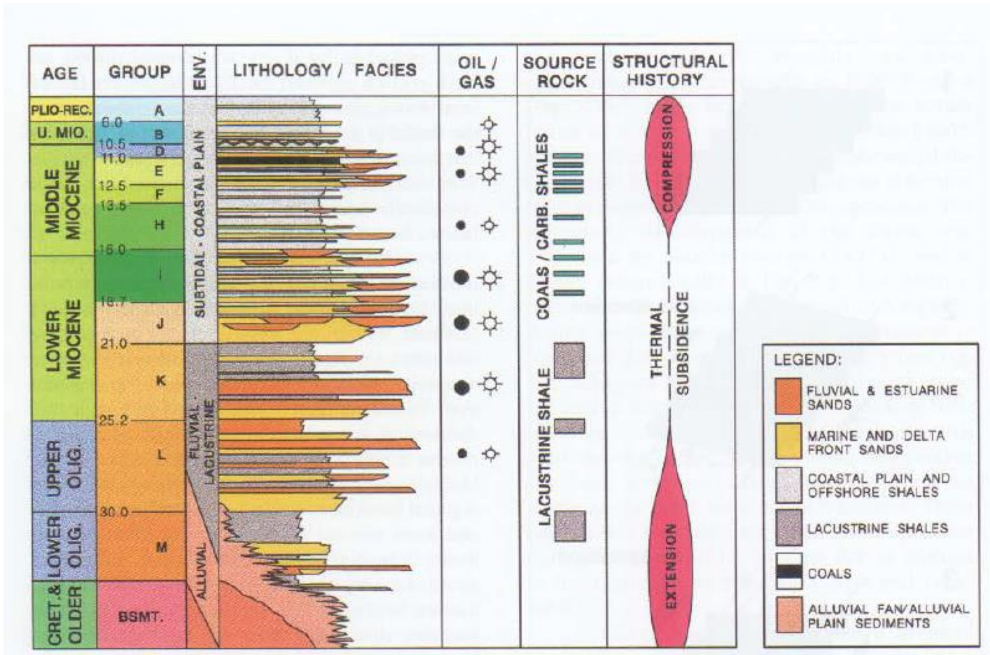


Figure 3: Generalized stratigraphy in Malay Basin (Petronas, 1999)

The major source rock for hydrocarbon generation in Malay Basin come from lacustrine sediment from group M, L and K, and fluviodeltaic sediment that was deposited in Group I and E (Muhammad & Jamil, 2010). The lacustrine source rock from Group M, L and K comprise of shale that rich in freshwater and marine algal component. Most of the hydrocarbon that originates from Group M, L and K are common in the southeastern area which is the flanks side of the basin. Group M, L and K are generally within the oil window in much of the basin margins and become over mature towards the basin center.

A cyclical succession of offshore marine, tidal estuarine, coastal plain and fluvial environment was deposited in the lower to Middle Micence. Group I and J consist of progradational to aggradational fluvial to tidally dominated estuarine sands. Group F and H are dominantly marine to deltaic sediments with fluvial/estuarine channels, deposited during an overall see level rise. Group E and D were deposited by the progradational stacking of dominantly fluvial/estuarine channels, and culminated with a localised erosional unconformity.

Log Motifs

In recent times, the shapes of gamma ray are becoming more important as these have been found to be very variable, show greater detail and are related to the sediment character and depositional environment. The Gamma ray log is frequently an indicator of shale content. This is related to the clay content. A bell shaped log with gamma ray value increasing upwards to a lower value indicates increasing clay content. A funnel shape with the values decreasing regularly upwards shows a decrease in clay content. The decrease in clay content is correlated to an increase in sand content and grain size. Shapes on the Gamma ray log can be interpreted as grain size trends and by sedimentological association as cycles. A decrease in gamma ray value will indicate an increase in grain size. Small grain size will correspond to higher gamma ray values. The sedimentological implication of this relationship leads to a direct correlation between facies and log shape.

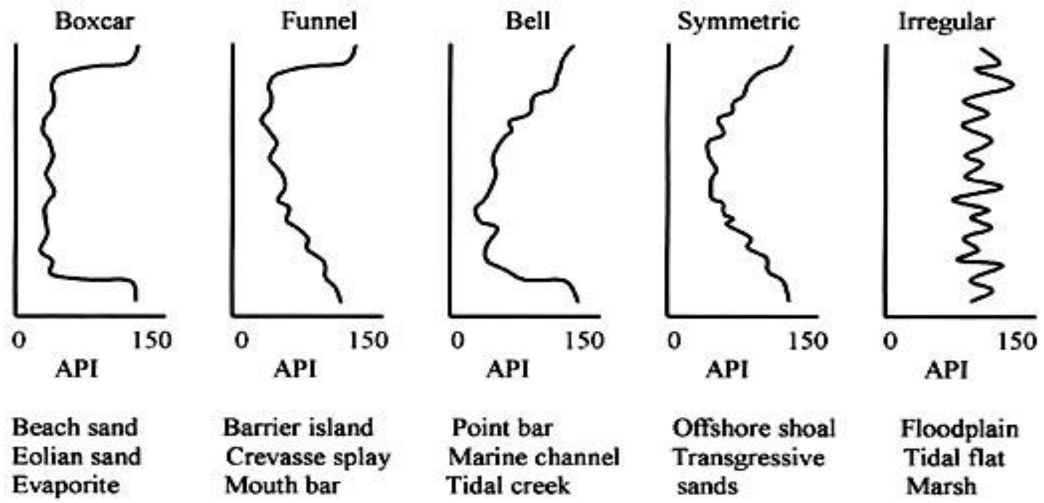


Figure 4: Log Motifs

Reservoir Characteristics

In the oil and gas industry, reservoir characterization involves the analysis or assessment of petroleum reservoir behaviour, for the purposes of improving estimation of reserves and making decisions regarding the development of the field. (Web Definition, 2014).

Porosity, temperature and volume of shale with regards to the gamma ray calibrated are some of the reservoir behaviours that will be discussed in this project. The porosity of a rock is the fraction of the volume of space between the solid particles of the rock to the total rock volume. The space includes all pores, cracks, vugs, inter- and intra-crystalline spaces. The porosity is conventionally given the symbol f, and is expressed either as a fraction varying between 0 and 1, or a percentage varying between 0% and 100%. Sometimes porosity is expressed in 'porosity units', which are the same as percent (i.e., 100 porosity units (pu) = 100%).

Porosity is calculated using the following relationship:

$$\mathrm{f} = \frac{V_{pore}}{V_{bulk}} = \frac{V_{bulk} - V_{matrix}}{V_{bulk}} = \frac{V_{bulk} - \left(W_{dry} / \mathrm{r}_{matrix}\right)}{V_{bulk}},$$

Where:

Vpore	= Pore volume
Vbulk	= Bulk volume
Vmatrix	= Volume of solid particles composing the rock matrix
Wdry	= Total dry weight of rock
Rmatrix	= Mean density of the matrix minerals

A porous rock has the capacity to hold fluid. By definition, reservoirs must be porous. Porosity is the void space in the rock, reported either as a fraction of one or as a percentage. Most reservoirs contain >0% to <40% porosity. (Gluyas, J. G & Swarbick, R., 2006)

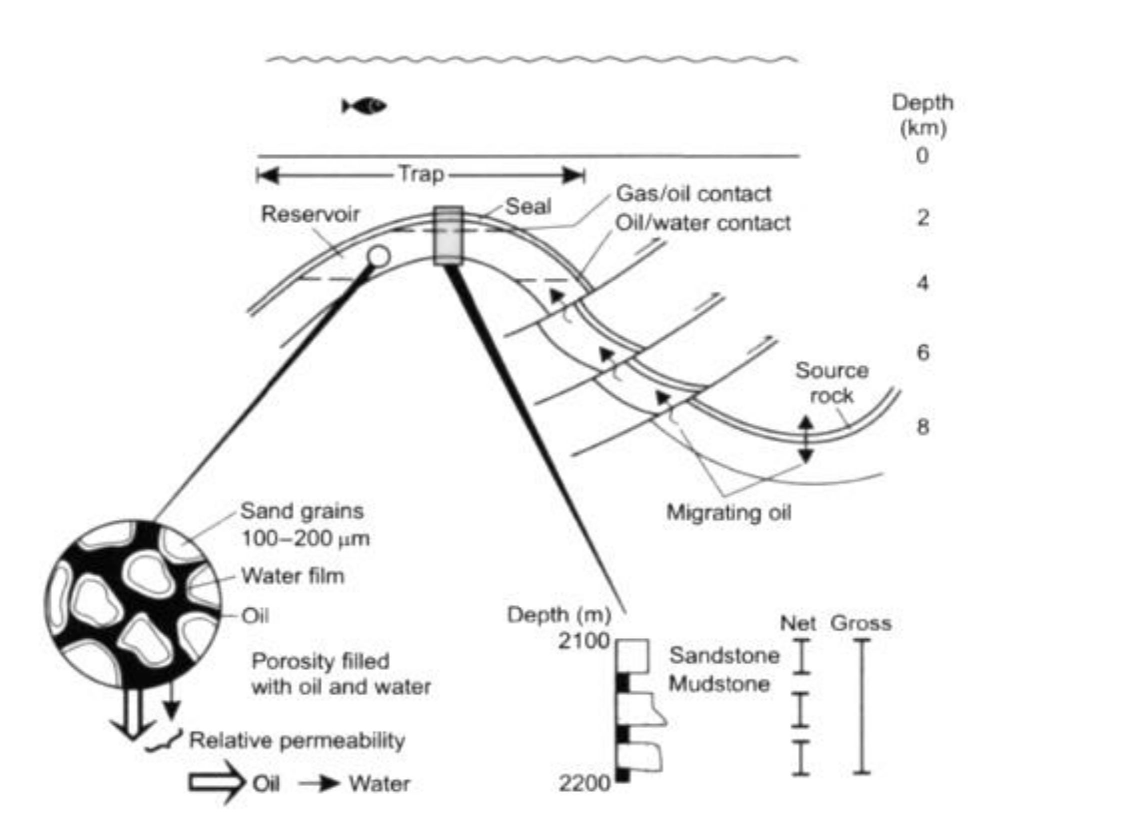


Figure 5: Cross section of part of petroleum-bearing basin showing the reservoir characterization over depth with relation to the petroleum system.

Temperature is an average value of energy for all the atoms and molecules in a given system. Temperature is independent of how much matter there is in the system. It is simply an average of the energy in the system (ED informatics, 2014).

Temperature gradient, also known as a geothermal gradient which is the rate of increase in temperature per unit depth in the Earth. Although the geothermal gradient varies from place to place, it averages 25 to 30 °C/km [15 °F/1000 ft]. Temperature gradients sometimes increase dramatically around volcanic areas. It is particularly important for drilling fluids engineers to know the geothermal gradient in an area when they are designing a deep well. The downhole temperature can be calculated by adding the surface temperature to the product of the depth and the geothermal gradient (Schlumberger Glossaries, 2014).

One of the factors affecting the temperature distribution within the crust is the anisotropy of the thermal conductivity (Kappelmeyer & Haenel 1974; brmcik & Rybach 1982). Its effect is generally believed to be very small and of the second order compared with other disturbing effects, such as inhomogeneities of thermal conductivity or heat sources, uplift and erosion, underground water movement, long-term variations of the ground surface temperature. The calibration of temperature and thermal conductivity as well as pressure distribution and fluid flow path within the sedimentary sequence will be part of this project.

Thermal conductivity is the measurement of the rate of energy transfer across a unit area under the potential of a unit temperature gradient which has been expressed in units of $W(m^oK)^{-1}$. It is a property of matter and in rock specimens, its value is dependent on direction of measurement since the rock are anisotropic (Jessop, 1990). If the thermal conductivity of the sediments is known, the heat flow can be calculated using the heat flow equation. In practice, the thermal conductivity is often estimated from a look-up table of common values.

Heat transport is governed by the thermal conductivity of the rocks, which varies for each lithology and in porous sediments due to the fluid contained therein. High conductivity rocks include salt, quartzite, and some ultra- basic rocks. Low-conductivity rocks include coal and many mudrocks and shales. Water has a low conductivity relative to many rocks, but it is high in comparison with oil, and particularly with gas.

The heat flow through rocks can be expressed as the products of temperature gradient and thermal conductivity and is given by Fourier's Law. It states that the heat flow, Q is directly proportional to the temperature gradient in the form of

$$Q = K(dt/dz),$$

where Q is heat flow, K is thermal conductivity, and t is temperature at depth z.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

The primary source of data collected in this study was derived from the analysis of well logs survey of oil and gas drilled in several fields in Malay Basin. 3 wells with summation of 254 raw data to be analysed (62 stations from S field, 94 stations from T field and 98 stations from J field). These logs were interpreted to determine depositional setting, distribution patterns, depositional environments and petroleum geology for the Central of Malay Basin. This well data mainly provided by supervisor of my research project.

Throughout completing this project, the following is the step-by-step methodology.

1. A map is developed. This map model is necessary as it gives the understanding and observation on where the 3 wells are located.
2. Gamma ray log is generated to study about the depositional environment and lithology of the formation.
3. A graph of stimulated data is constructed to show the reservoir behaviour; porosity-depth relationship and other variation of variables related.
4. Analysis of porosity vs volume of fines to study about the porosity for every lithology; sandstone, siltstone and shale.
5. Analysis of temperature versus depth.
6. Compare all the parameters related with gamma ray. All the data gathered is compared with the Kelantan Delta as an analogue.

Project concluded.

3.2 Gantt chart and Key Milestone

FYP 1

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic								Mid-semester break							
2	Preliminary Research Work															
3	Submission of Extended Proposal															
4	Proposal Defence															
5	Project work continues															
10	Submission of Interim Report															

Suggested Key milestone

FYP process

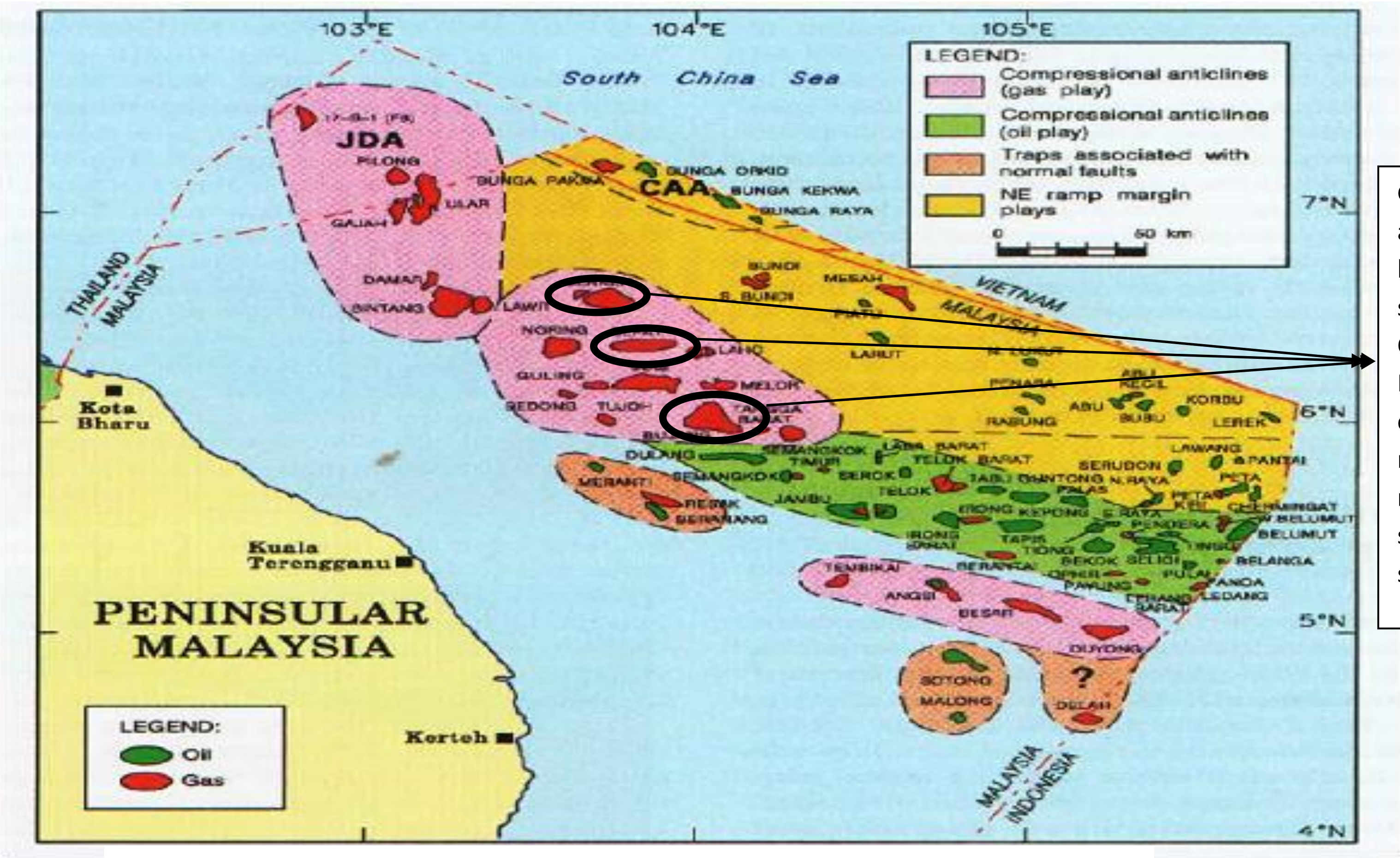
FYP 2

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Project Work Continues															
2	Submission of Progress Report															
3	Project Work Continues															
4	Pre-Sedex															
5	Submission of Draft Report and Technical Paper draft															
6	Submission of Dissertation (soft bound) & Technical Paper															
7	Oral Presentation- VIVA															
8	Submission of Project Dissertation (Hard Bound)															

Suggested Key milestone

FYP process

CHAPTER 4: RESULTS



Gas fields, named S, T and J are the 3 fields been analyzed in this study. Located at the Central of Malay Basin which considerably deeper, much thicker, hence more deeply buried sedimentary succession.

Figure 6: Distribution map showing the trap style and play types in Malay Basin

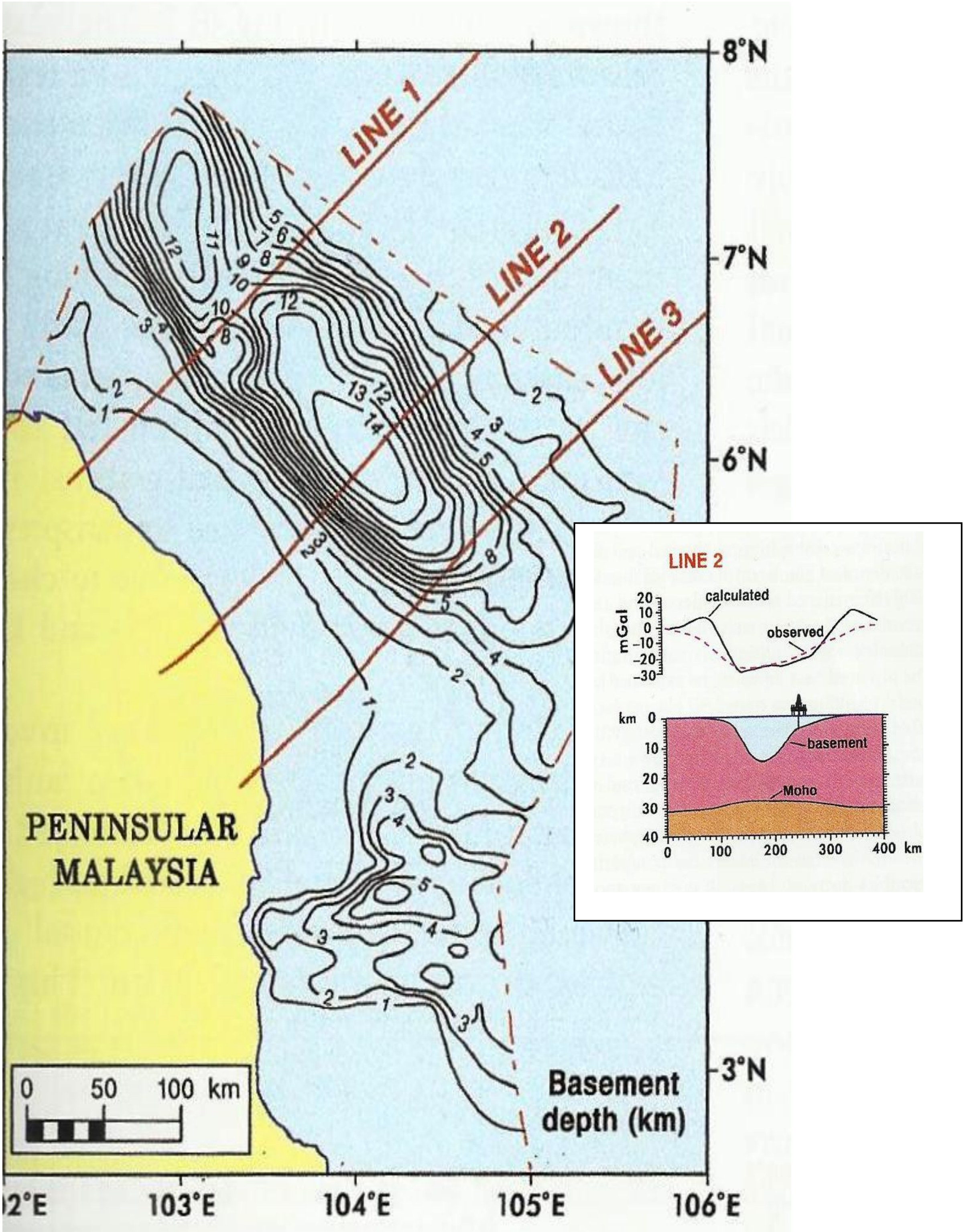


Figure 7: Countour map and cross section showing cross section in Line 2

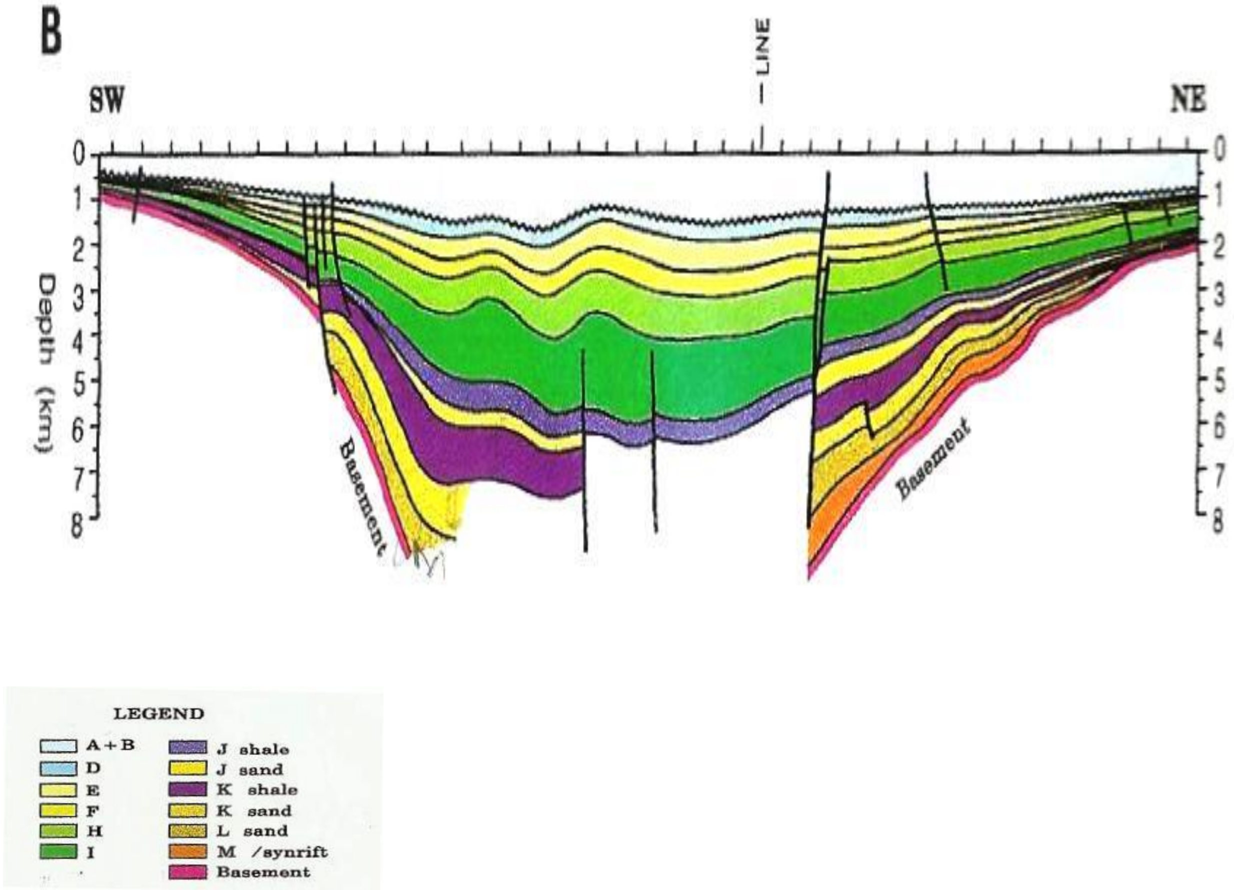


Figure 8: Cross section (Line 2) of the Malay Basin in the study area which shows that the centre part of Malay Basin is thicker than the Southwestern and Northeastern flank that formed during the basin inversion phase in the middle of Eocene. (Modified after Esso, 1985)

4.1 Thermal Conductivity Property

Temperature in the sub-surface increases with depth. The rate at which it does so is called the *geothermal gradient* or *geotherm*. Typical geotherms for reservoirs are about 20 to 35 ^{0}C/km, although significantly higher values (up to 85 ^{o}C/km) can be found in tectonically active areas, and lower ones (0.05 ^{0}C/km) in stable continental platforms. Hence, the bottom hole temperature (*BHT*) for a 3000 m well with a geotherm of 25 ^{0}C and a surface temperature of 15oC is 90 ^{0}C. (Dr Paul Glover, 2010).

Note that this assumes that the geothermal gradient is constant. In practice this is rarely the case because of differences in the thermal conductivities of rocks between the bottom of the hole and the surface, and fluctuations in the surface temperature which penetrate the sub-surface and perturb the sub-surface temperature. Low thermal conductivity rocks, such as shale, act as a thermal insulator and have a large temperature gradient across them, while high thermal conductivity rocks, such as salt, permit the conduction of heat efficiently, and have a small temperature gradient across them.

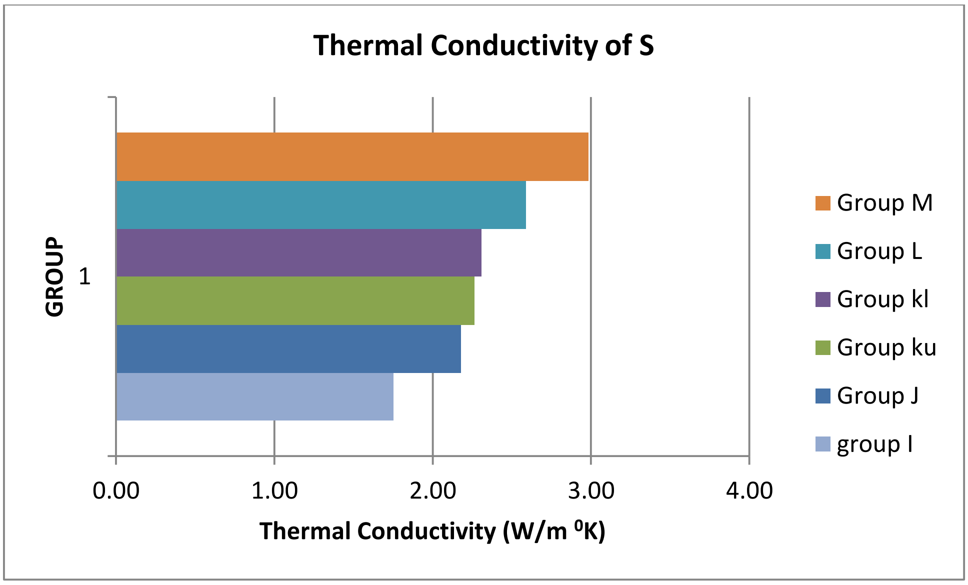
4.2 Factors that affect thermal conductivity

For sedimentary rocks (Figure l a) the controlling factors on thermal conductivity are porosity and origin of a particular sediment. It appears as if chemical sediments, mainly formed by precipitation of dissolved minerals or by compaction of organic material, and low porosity (< about 30 %) physical sediments, formed by the compaction and cementation of clastic material, have nearly identical frequency distributions, means, and medians. In contrast, high porosity (> about 80 %), mainly marine physical sediments display a distribution which is biased towards low conductivities, with mean and median about half the size of the former two. This, of course, is due to the low-conductivity fill of the void space, which can be either air or water.

Depth of Burial

In clastics, thermal conductivity is normally likely to increase with depth of burial, if only compaction is the main factor which determines the variation in porosity with depth (Palciauskas, 1986). It has been observed that the average thermal conductivity in central Malay Basin increases with depth. For S field, the lowest average thermal conductivity is

1.75 mW/m ^{0}K (Group I) and the maximum value of thermal conductivity is 2.98 mW/m ^{0}K (Group M). While in T field, minimum thermal conductivity is 1.68 mW/m ^{0}K (Group AB) and the maximum value is 2.47 mW/m ^{0}K (Group E). Central Malay Basin has experienced a normal sedimentation history and relatively normal compression zone which disrupted often by overpressured zones only at depth near the bottom of the well.



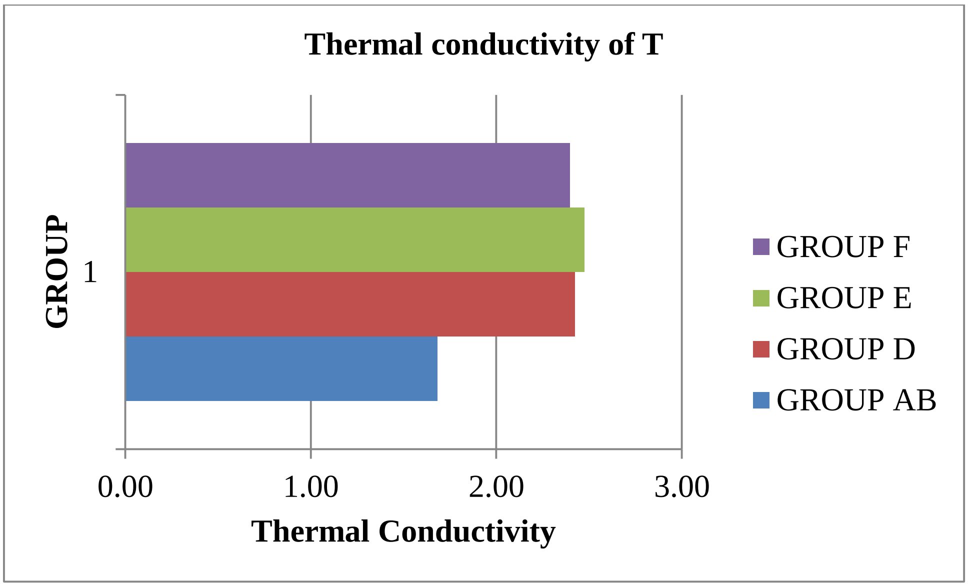


Figure 9: Comparison of average measured thermal conductivity for 2 fields in Central Malay Basin

Porosity

As referred to by Stefansson (1997), the thermal conductivity of rocks is highly dependent upon porosity. The variation in thermal conductivity measurements for various different rock types (Cermák and Rybach, 1982) is largely due to the variation in porosity of the rock samples measured. An empirical relationship between thermal conductivity and porosity is given by

ϕ = Porosity, here as fraction;
K = Thermal conductivity [$Wm^{-1}{}^{\circ}C^{-1}$];
K_w = Thermal conductivity of water [$Wm^{-1}{}^{\circ}C^{-1}$];
K_r = Thermal conductivity of rock matrix [$Wm^{-1}{}^{\circ}C^{-1}$]; and
$r = \frac{K_r}{K_w}$ = The ratio between the thermal conductivity of the rock matrix and water.

The weighted average or linear equation:

$$K = \phi K_w + (1 - \phi) K_r$$

The harmonic average equation:

$$\frac{1}{K} = \frac{\phi}{K_w} + \frac{(1-\phi)}{K_r}$$

The geometrical average equation:

$$\log K = \phi \log K_w + (1 - \phi) \log K_r$$

Maxwell's equation:

$$K = K_r \left(\frac{(2r + 1) - 2\phi (r - 1)}{(2r + 1) + \phi (r - 1)} \right)$$

The wide variations in average reservoir porosity within each depth range reflect the extreme ranges in porosity- controlling factors such as depositional facies, early diagenetic histories, geothermal gradient and degress of uplift from previous maximum burial that exist in the Earth's petroleum reservoir.

Therefore, estimation of average porosity for every field is calculated to easily observe the trend of thermal conductivity over porosity

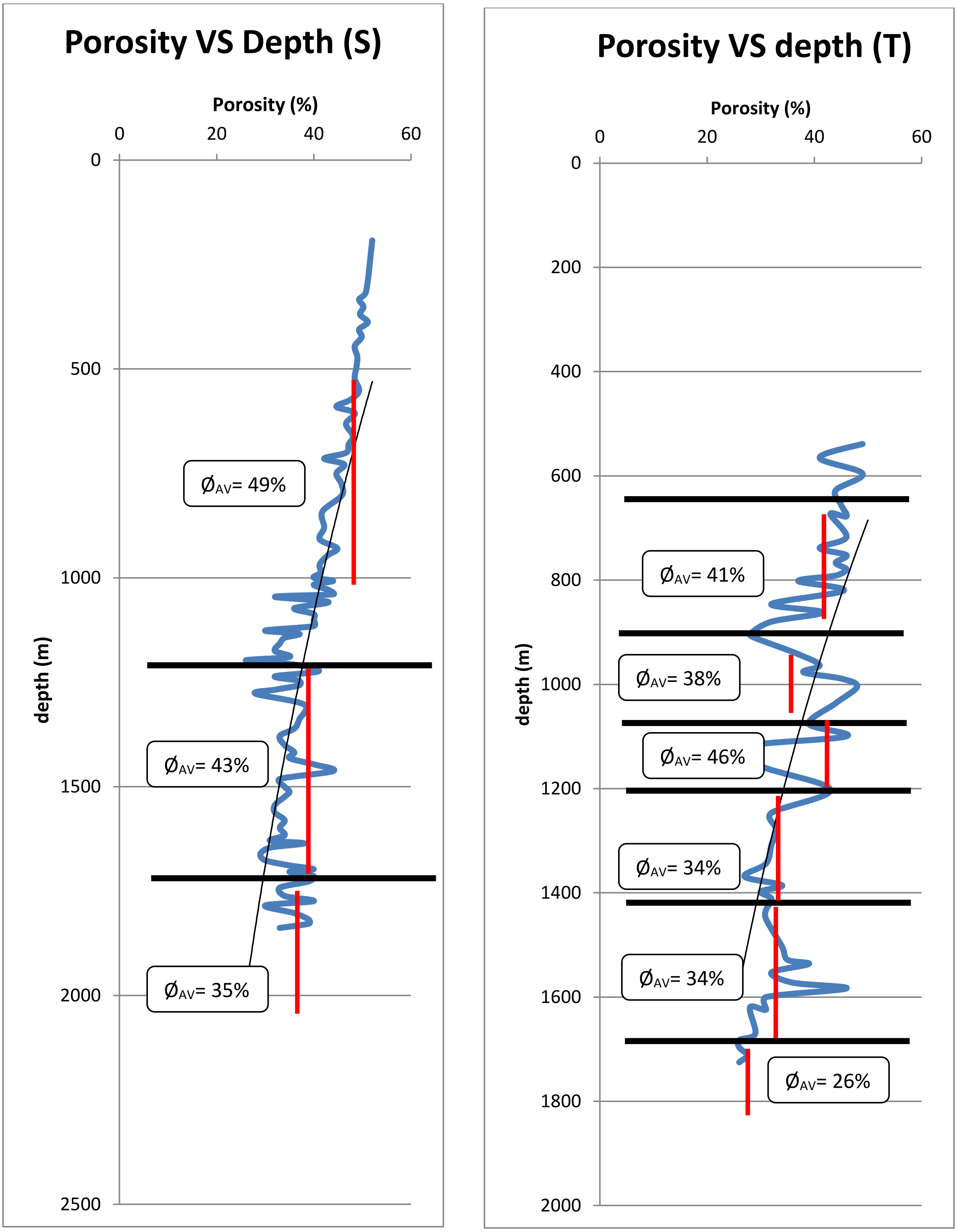
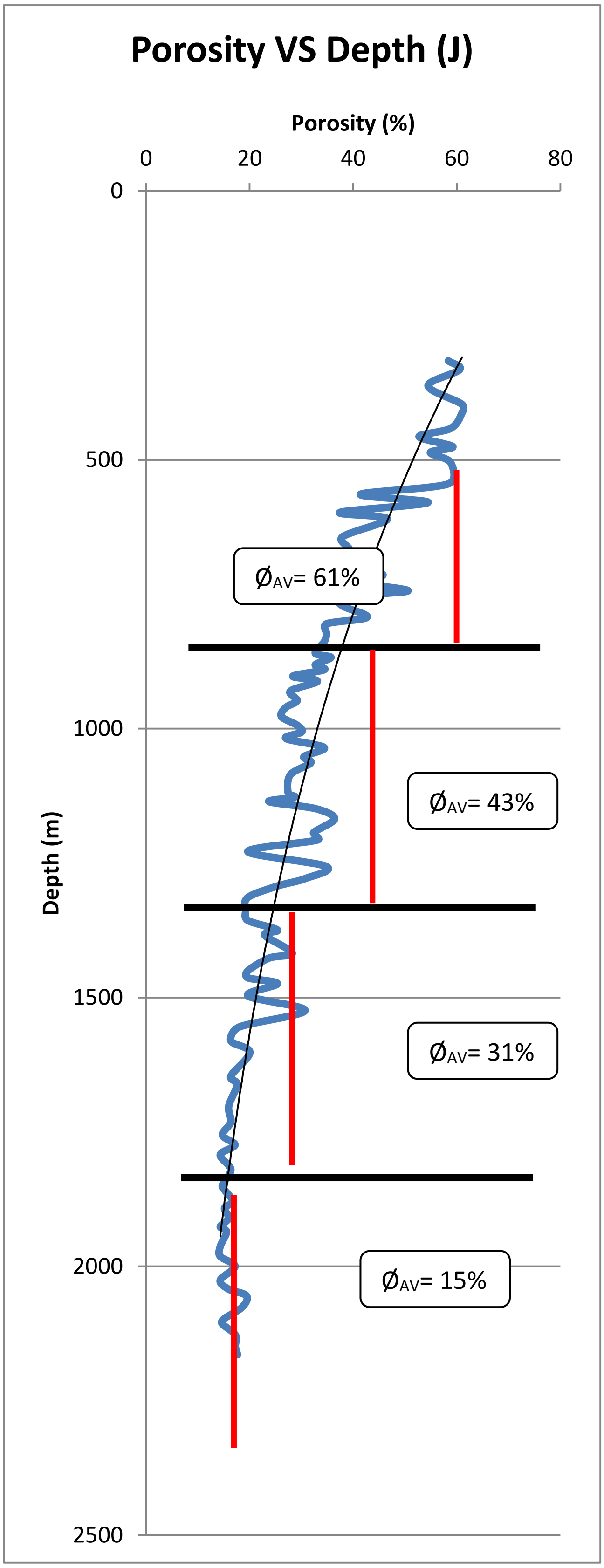


Figure 10: Depth versus porosity to obtain the average porosity at particular depth (following the seismic group of particular field)



The calculated porosity and average porosity values shown in figure above highlight that porosity decreased with increasing porosity.

As can be observed from the T Field plotted graph, the porosity in the first interval is the most highest with 49% while the third interval having the lowest porosity when the depth increasing.

For S field, the porosity distribution in second and third interval showing a little bit shifted from the theoretical facts. This might be due to the tool problems. However, the logarithm trend is still showing that porosity decrease with increasing temperature.

Furthermore, through observation from J field, the trend confirmed the theoretical observation. Highest porosity in the upper part of the reservoir and decreasing through the end might be due to rock compaction.

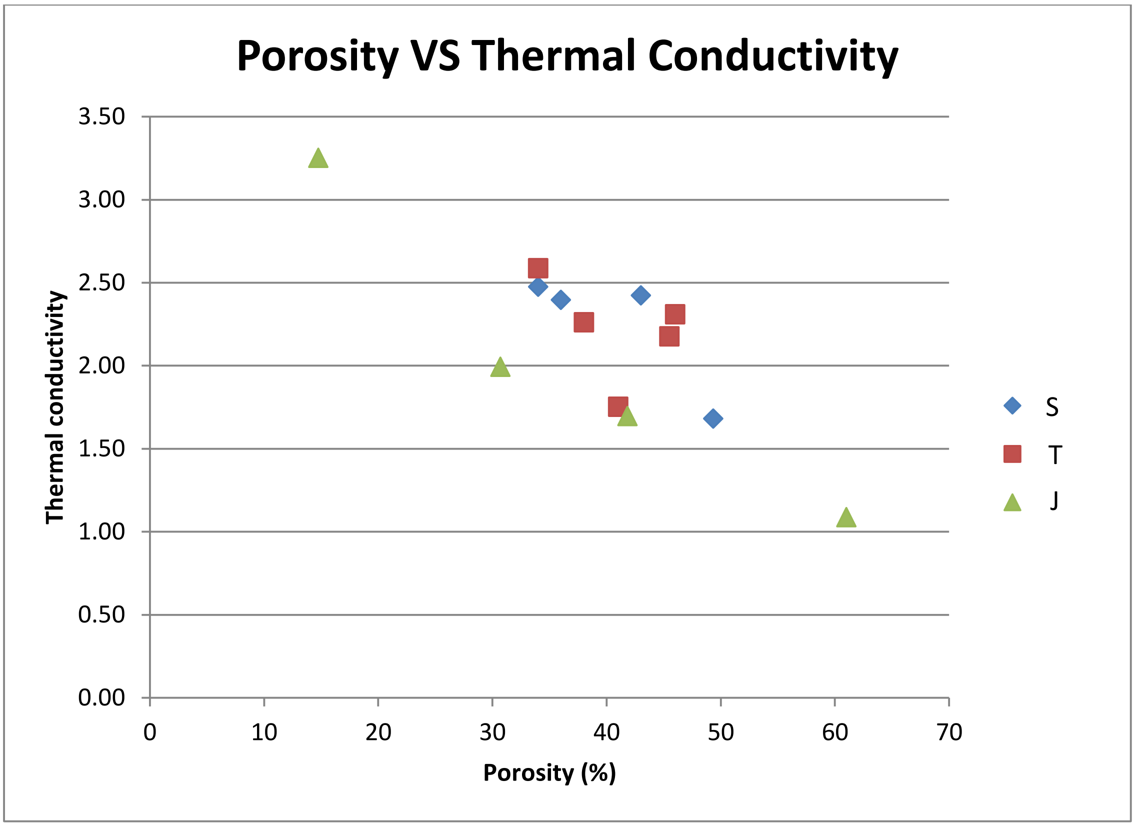


Figure 11: thermal conductivity as a function of porosity

Figure 11 shows thermal conductivity as a function of porosity for the 3 fields in Central Malay Basin. It may be noticed in figure that the thermal conductivity decreasing with increasing porosity.

The effective medium theory is a means to describe properties of a composite material from which the fractions of the individual components and their properties are known. An effective thermal conductivity, K for a randomly inhomogeneous medium made of constituents with volume fractions, V; and thermal conductivity's, k; is

$$K\text{-}1 = 3V_i\,(2K+k_i)^{-1}$$

where it is assumed that on a scale much larger than the grain size, the composite is homogeneous and isotropic. This has an advantage over the previous empirical formula since it is applicable for any number of components, any distribution of volume fraction and all values of the individual conductivities (Palciauskas, 1986)

Hence, according to the effective medium theory, in a normally compacting basin, the theoretical effective thermal conductivity is higher for compacted sediment. Compacted sediment is expected to have the lowest porosity at any specified depth.

Temperature and geothermal gradient

The temperature of an object or fluid is that property which determines the direction of the flow of heat from that body or fluid to an adjacent body or fluid with which it is in contact. Thus, heat flows from a body or fluid of higher temperature to a body or fluid of lower temperature. Temperature is one of the main parameters of state which defines the thermal state of the system. The temperature of all parts of the system in thermodynamic equilibrium is the same. Based on the molecular-kinetic approach, the temperature of a system characterizes the intensity of thermal motion of atoms, molecules and other particles forming the system.

For instance, for a system described by the laws of classical statistical physics the mean kinetic energy of thermal motion of particles is directly proportional to the absolute temperature of the system. In this regard we can say that the temperature characterizes the thermal motions within a body. In thermodynamics the reciprocal of the derivative of the entropy S of a body with respect to its energy E is called the absolute temperature T:

$$\frac{dS}{dE} = \frac{1}{T}$$

Temperature, like entropy, is a purely statistical quantity and makes sense only for macroscopic bodies. According to the second law of thermodynamics, energy is transferred from bodies with higher temperature to bodies with lower temperature. The absolute temperature is always positive, $T > 0$. The least *absolute temperature* possible is the absolute zero. At absolute zero, the translatory and rotary motion of atoms and molecules comes to an end, and they are in a state of the so-called "zero vibrations" rather than in a state of rest. By Nernst theorem the entropy of any body becomes zero at absolute zero temperature. Absolute zero is unattainable. The entropy S is a dimensionless quantity and from above equation follows that temperature has the dimensions of energy and can be measured in Joules. The ratio Joules/Kelvins (K) called Boltzmann's constant k is equal to $k = 1.38 \times 10^{-23}$ Joules/K.

Thermal conductivity of materials is temperature dependent. The reciprocal of thermal conductivity is called thermal resistivity. Thermal properties connect temperature and heat flow, whick are the fundamental concepts in physics and classical thermodynamics. Temperature is the measure of the average energy content of macroscopic bodies; liquid, solid and gases. While heat flow represents the transfer of thermal energy between bodies or regions at different temperatures.

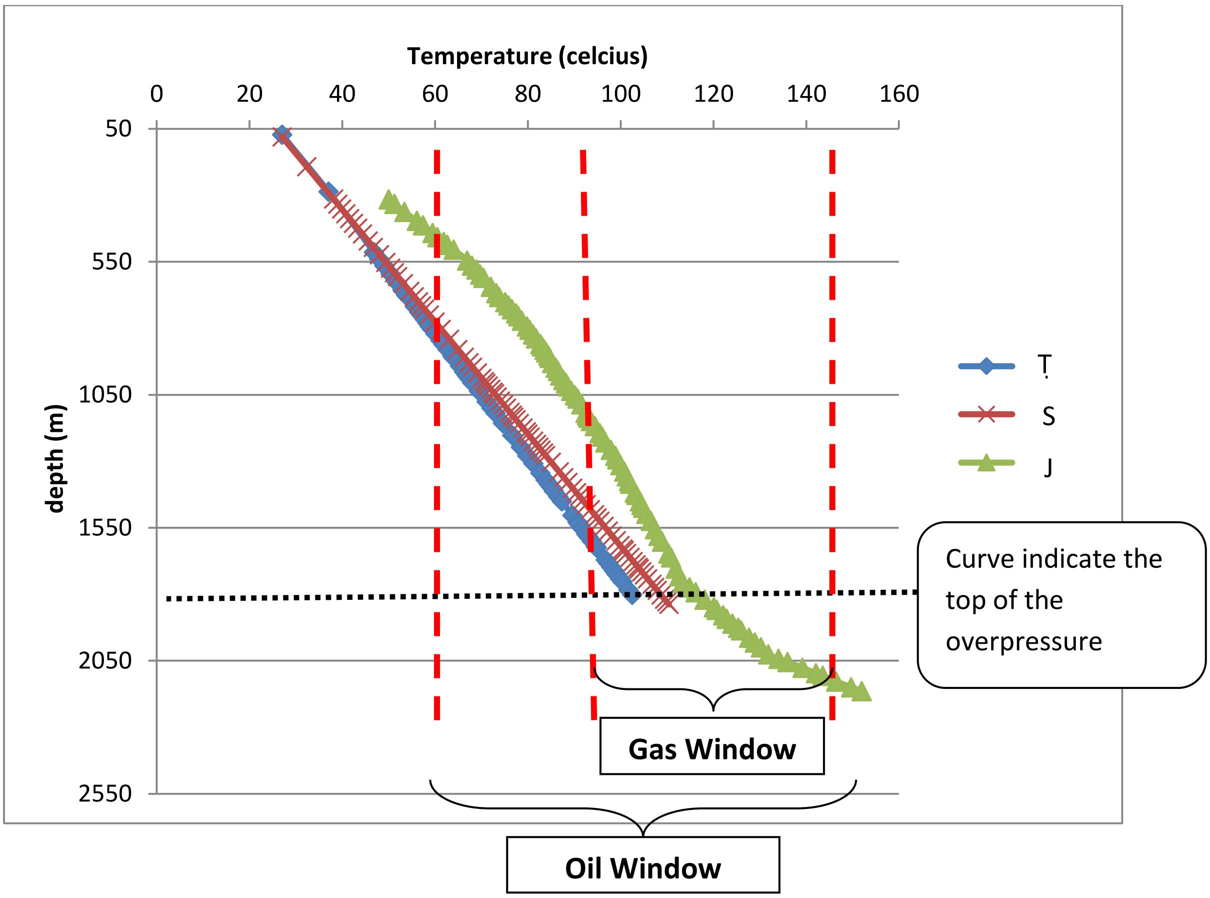
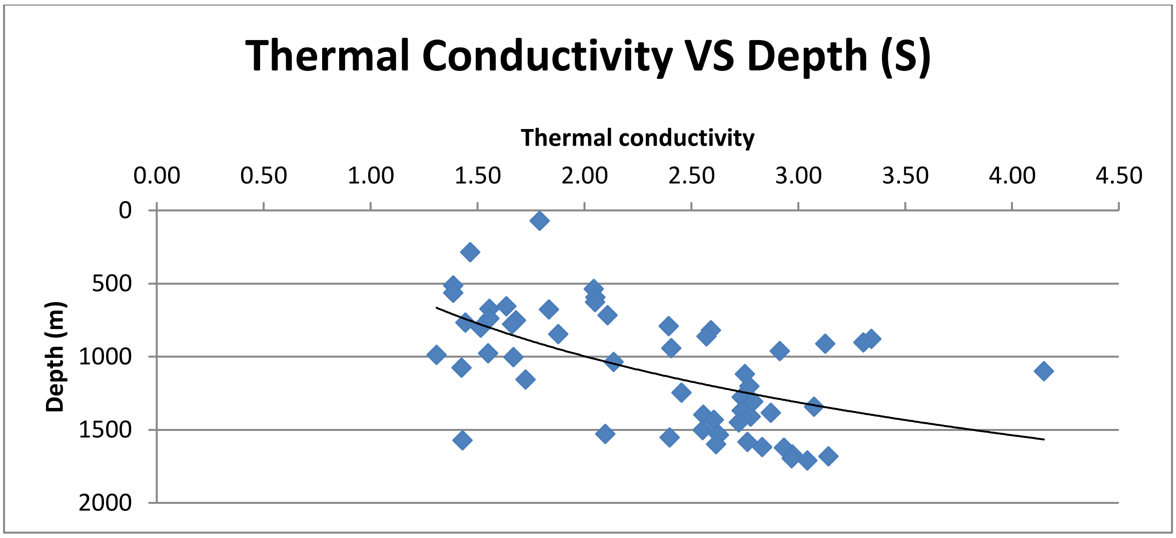
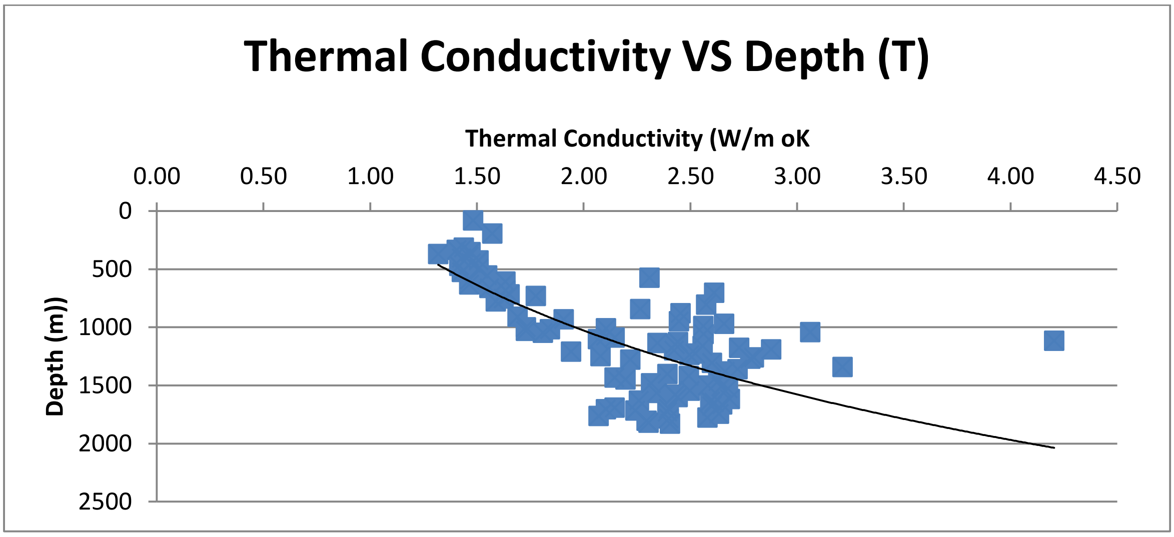


Figure 12: Graph of Temperature versus depth

From figure 12 above, it highlights that temperature increasing with increasing temperature. The character of vertical depth profile of temperature helps in understanding of the subsurface processes such as fluid flow. In addition, it can also be used to provide the information about oil (60-150 degree celcius) and gas window (90-150 degree celcius).

As can be seen from the graph, the trend of Jerneh Field showing a concave upward of temperature profile correspond to a prominent lateral movement of fluid. Besides, the temperature profile can also infer the intervals of seal and reservoir. Typical temperature profile of Jerneh can also be interpret to have an overpressure at the stand of the curve which is at depth approximately 1770 ± 3 metre as shown by the dotted black line above. Under ambient conditions, the fault is at high pressure relative to downthrown reservoirs. A pulse of high-pressure fluid ascending the fault lowers effective stress in the fault zone sufficiently to produce a significant transient increase in permeability (Steven L., Lorraine B. E., Martin S., James R. W., 2004)





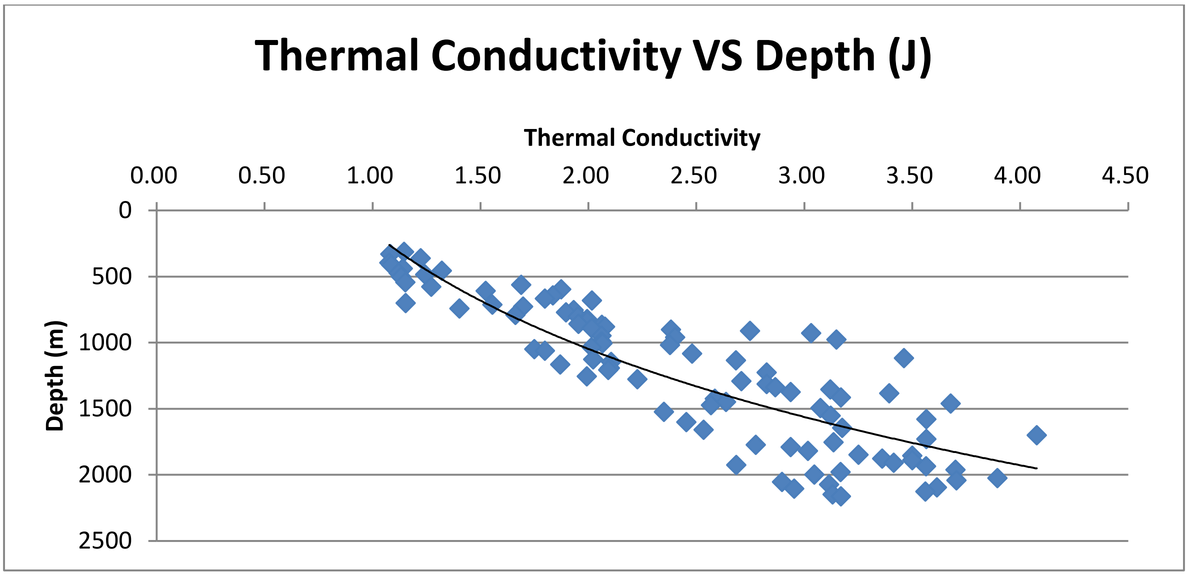


Figure 13: Depth versus thermal conductivity for every field analysed.

As can be seen from the figure above, thermal conductivity is relatively constant over a narrow temperature range. As the temperature increases at a specified depth, however, the rate at which particles in the substance are moving increases, and the rate at which heat is transferred typically increases as well as the depth increases and compaction occurred.

In order to observe the variation in temperature gradient, it was necessary to calculate the gradient directly from the measurement and no obvious scale variations could be seen in figure above.

<u>Calibration of measured thermal conductivity with gamma ray log for facies determination</u>

Measured thermal conductivity is one of the physical properties of sedimentary rocks which can be calibrated with well logs (Vacquier et al.,1988; Brigaud et al, 1990; Demongodin et al, 1991)

There can thus be a significant variation of the mineralogical content within one lithological unit. A core measurement is therefore not a good representation of an entire geological unit. Estimating a mean value for a geological unit based on only few point measurements of thermal conductivity is subjected to large uncertainty. Development of better tools is therefore needed. The problem can be viewed as a question of upscaling thermal conductivity from sample level to formation level. We propose to approach this by correlating thermal conductivity and well log data (Tectonor, 2009). Changes in the thermal conductivity are related to differences in porosity, texture and mineralogy.

Common petrophysical logs such as spectral gamma, density, neutron, and sonic are in some way also affected by the same parameters. In order to observe variations of thermal conductivity and facies deposition, measured data from Sepat field was taken into consideration. Figure below shows the measured thermal conductivity calibrated with well log to identify the relationship between those. In the correlation of measured thermal conductivity to log parameters, there are some constraints to get an acceptable degree of confidence in correlation because there is no sample of rocks available. This study is depends mainly on log data. The porosity data were used for the calibration to divided and identify the data into sandy and shaly subsets.

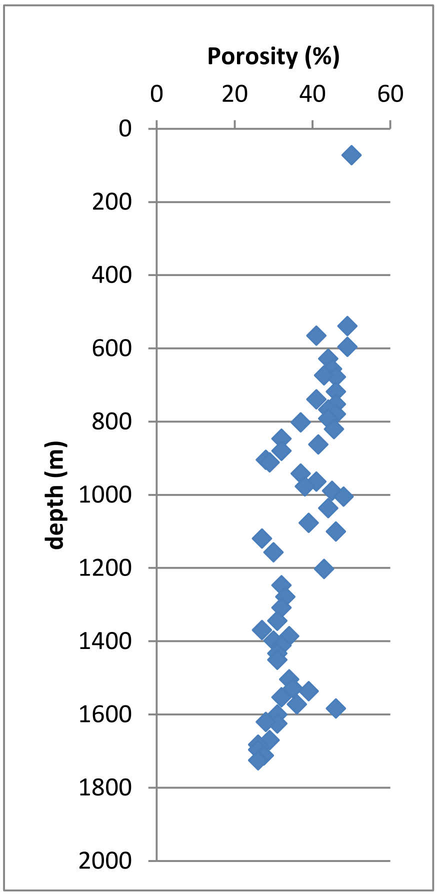


Figure 13: Depth versus porosity profile for S field

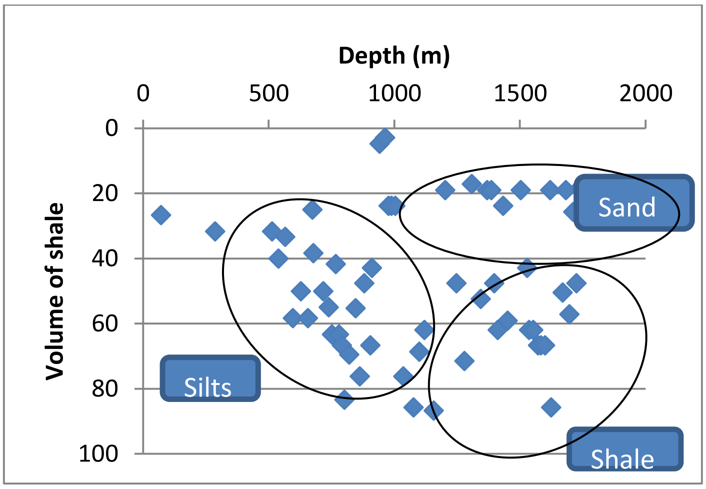


Figure 14: Depth versus volume of shale for S field.

Facies identification from volume of shale distribution graph with depth showing that sandy with less than 30% volume of shale distribute mainly at depth 1000-1700 metre having low porosity with average 30%. Shale with clay contain more than 40% concentrated at depth 1100- 1700 meters with maximum content reaching 100% of clay and having higher porosity than sandy subset. Meanwhile, at depth less than 1000 meters, silt is believed to be deposited with porosity higher than 35%. The content of shale volume is in the range of 25-80%.

In this study, an attempt to correlate thermal conductivity measurements to well log is made. Gamma ray used to calculate the shaliness or shale volume of the rock as been plotted in figure.

Shale volume is calculated in the following way: First the *gamma ray index*, I_{GR} is calculated from the gamma ray log data using the relationship

$$I_{GR} = \frac{GR_{\log} - GR_{\min}}{GR_{\max} - GR_{\min}}$$

where: I_{GR} = the gamma ray index
$GR_{\log}$ = the gamma ray reading at the depth of interest
$GR_{\min}$ = the minimum gamma ray reading. (Usually the mean minimum through a clean sandstone or carbonate formation.)
$GR_{\max}$ = the maximum gamma ray reading. (Usually the mean maximum through a shale or clay formation.)

Table 1: : The comparison among different lithologies used in predicting average thermal conductivity with the specified volume of shale and average porosity for S field.

Lithology	Volume of shale	Average Porosity	Average Thermal Conductivity
Sandstone	<30%	30%	3.0 W/m ^{o}K
Siltstone	25%-80%	40%	1.3-2.5 W/m ^{o}K
Shale	>40%	30%	2.75 W/m ^{o}K

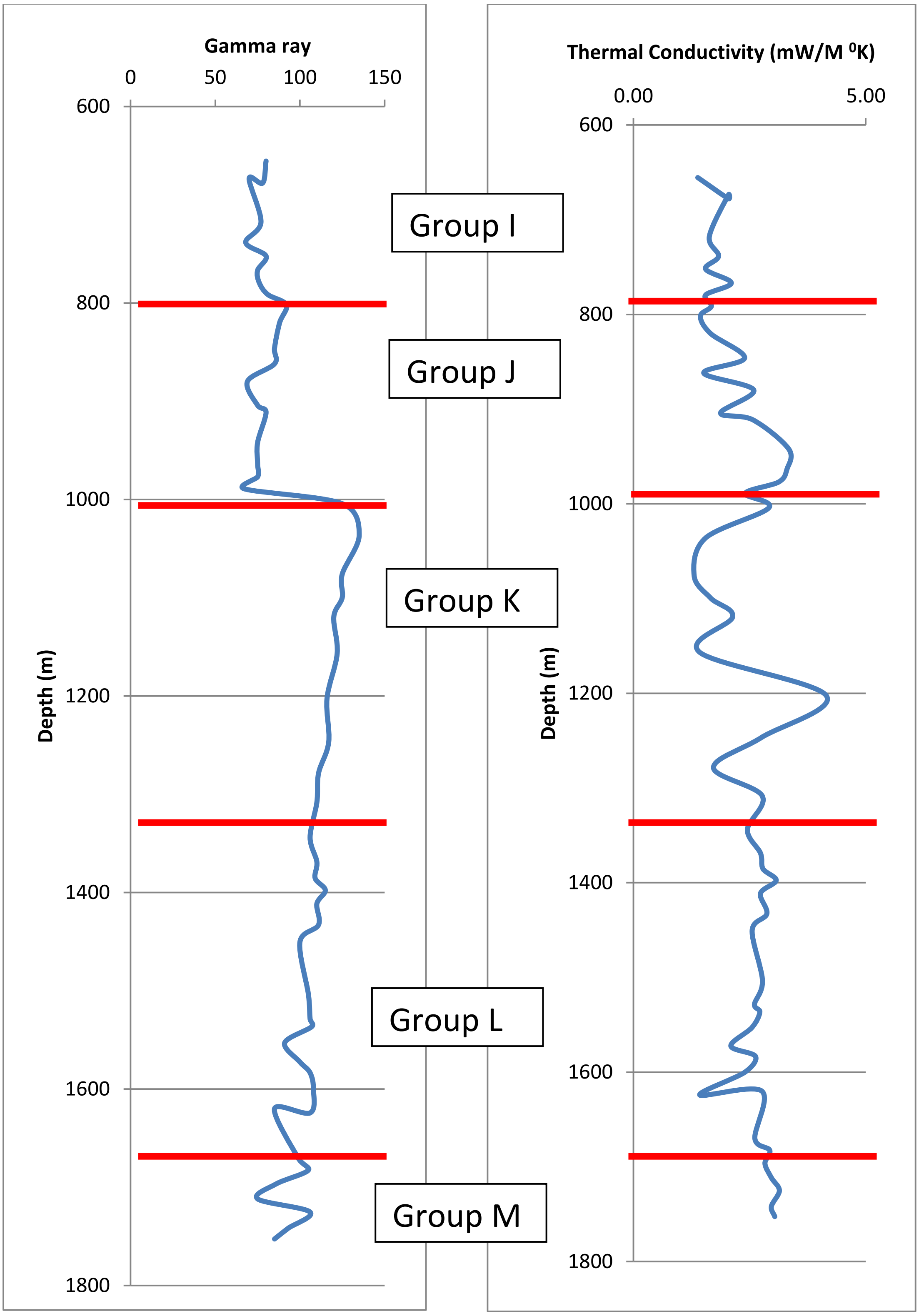
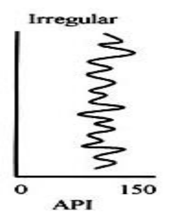
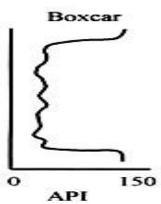
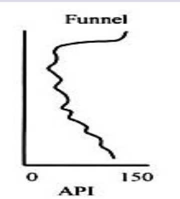
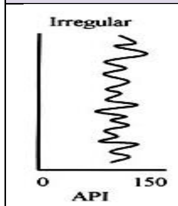


Figure 15: Calibration of gamma ray log with measured thermal conductivity according to the seismic group with response to the gamma ray pattern to evaluate the relationship between the thermal conductivity and the depositional environment.

Table 2: Interpretation of the relationship between the depositional according to the log response with the measured thermal conductivity, porosity and temperature

Log Motif Model	Log shape type	Group	Facies type	Depositional environment	Average Thermal Conductivity (mW/M ^{0}K)	Average porosity (%)	Average Temperature (degree celcius)
	Serrated blocky shaped	I	Intercallation (sandstone and siltstone)	Storm dominated shelf, distal marine slope	approx. 1.75	41	55
	Saw teeth/ serrated shaped	J	Thick sandstone interbeded siltstone, silt and clay	Fluvio deltaic plain, storm dominated shelf, distal marine slope	approx. 2.18	46	64
	Funnel shape	K	Beach sand, alluvial fans, barrier bars	Mouth bars,deltaic front and shoreface	approx. 2.23	42	75
	Irregular blocky shaped	L/M	Sandstone interbedded with siltstone and clay	Fluvio deltaic plane, deltaic front – prodelta, reworked offshore bars	approx 2.6	30	94

The average measured thermal conductivity in group I, J and K and L/M is 1.75, 2.18, 2.23 and 2.6 mW/m°K respectively (Table 2). Thermal conductivity value shows the increment over depth. The irregular trend of average porosity with depth is probably due to effect of diagenesis which overshadows the effect of compaction. In addition, it might be because of the high intercalation between sandstone and shale. A regular increase in thermal conductivity with depth is observed as the porosity is comparatively low. This might be due to the effect of compaction as the depth increasing. Furthermore, measured thermal conductivity observed to increase as the temperature increases.

Therefore, from the observations of the measured thermal conductivity versus stratigraphic age for different depositional environment, it seems quite difficult to relate thermal conductivity to either depth or depositional age for all the sequences. Any relationship between thermal conductivity and depth might be made for rocks within only a small interval of the stratigraphic sequence and confined to a uniform localized geological setting. When measured thermal conductivity is not available, the in situ thermal conductivity is therefore best described by considering the relationship of the porosity, matrix and fluid content with known thermal conductivity measured.

4.3 Kelantan Review

A site visit to several places located in Kelantan between 5^0 59' 44.9'' to 6^0 11' 54.0'' and 102^0 06' 15.1'' to 102^0 08' 21.1'' has been completed. About 12 samples were taken around Kelantan (see figure) for further research in order to analyse the geological and reservoir components in modern delta environment. This field work mainly focus on the Delta Environment which data will be used to compare with the reservoir characteristics in delta environment at Malay Basin.

Fields data were provided during three days fieldwork from 14 March to 16 March 2014. The topography of Kelantan delta is divided into several different morphologies; 40% area consist of lowland area, swamps, and other water bodies covered 20% and 40% of this area is high landform that underwent weathering.

According to Swan (1968), The coast, unprotected by headlands or offshore islands is completely exposed to waves from the South China Sea, has a concave sector at Sungai Semerak, a protrusion at Pengkalan Datu and an irregular coastline of deltaic islands, spits and a lagoon at Tumpat. The low-lying coastal plain is very wide, composed of a 10km outer belt of barrier and deltaic deposits backed by a 30km wide alluvial plain whose surface is often interrupted by abandoned levees and meander scrolls.

The coastal alluvium is deep, attaining more than 100m along the outer edge of the plain. A 15m deep unbottomed borehole near the beach records an upper layer of sand, succeeded downwards by sandy clay and clay. The sands were iron stained and unsuitable for glass making. The common heavy minerals were ilmenite, amphibole, tourmaline, magnetite, zircon and rutile. Pyrite and foraminefera, commonly pyritised, increases with increasing depth (Chu 1975).

Besides, the major objective of this fieldtrip is to collect samples for further analysis on the reservoir element of the soil collected. Below are some of the pictures taken during the fieldtrip. Samples collected will be analysed by seizing and many else.

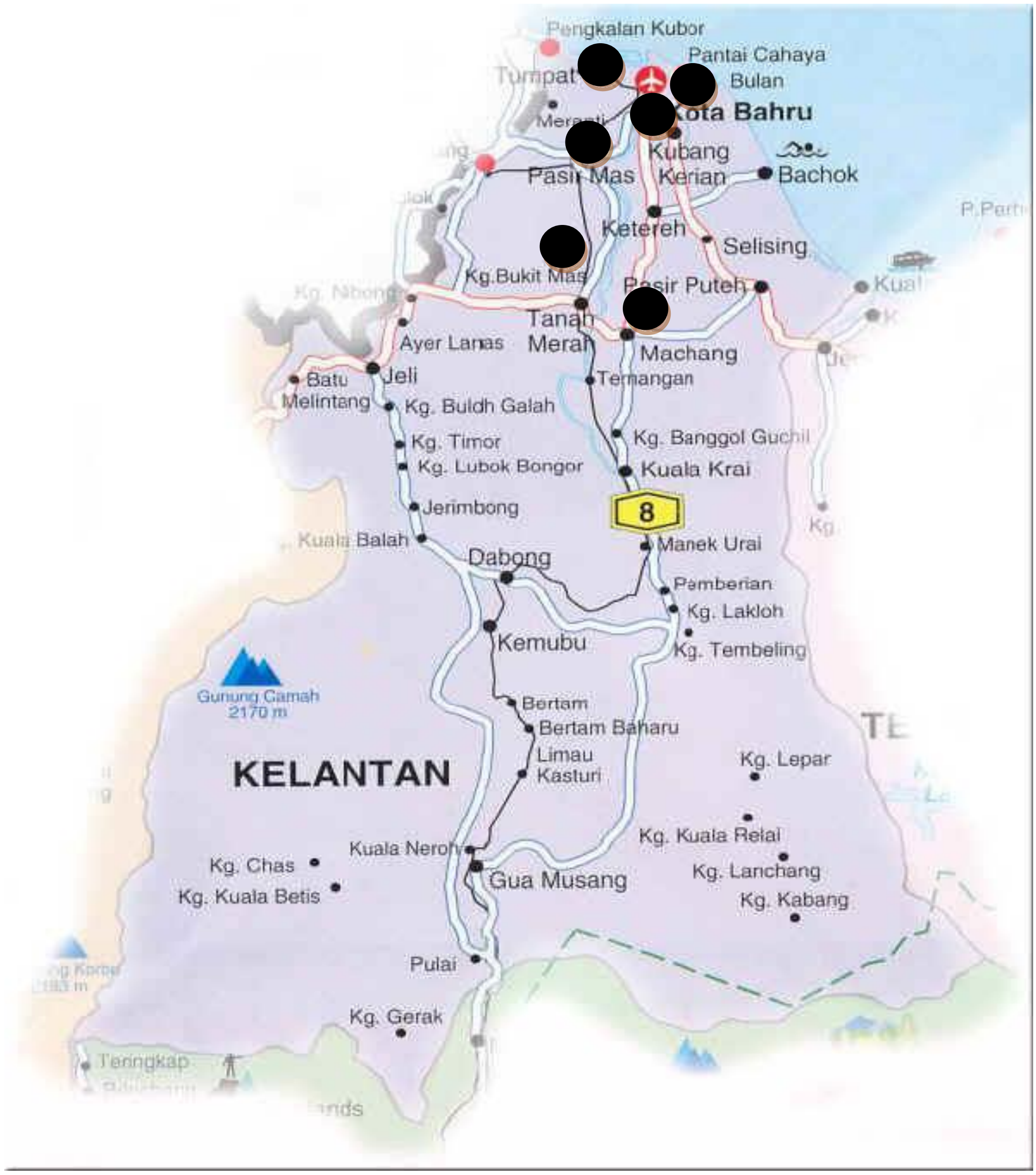


Figure 16: Some of the places went to collect the samples (Black dot). Most of the places located near to the Kota Bharu as it is where the sediment supply is abundant; the Delta environment starting to form.

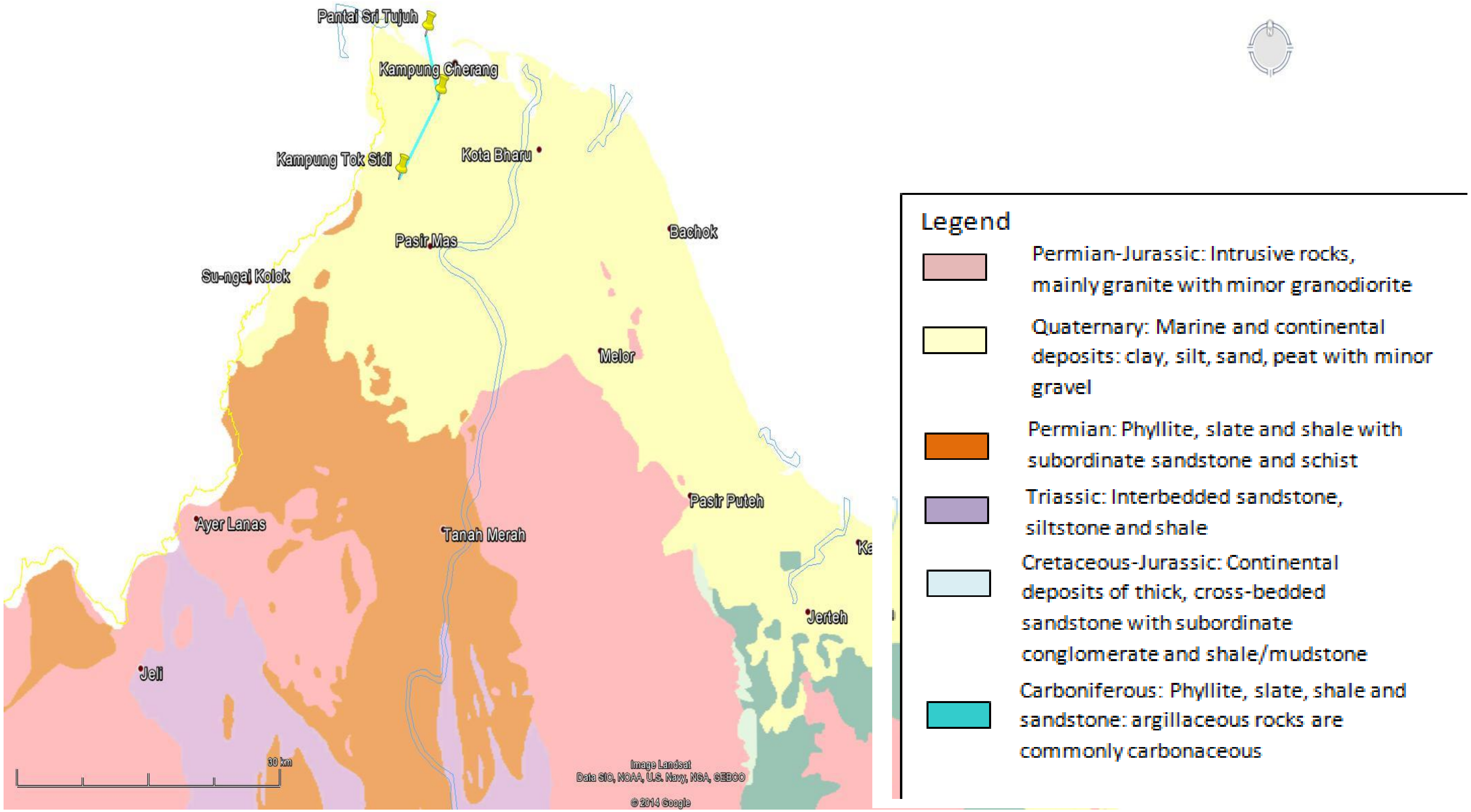


Figure 17: Lithology Map of Kelantan Delta (Google Earth)

Figure 18: Strata of the succession found in Pantai Mek Mas

Figure 19: High energy environment in Pantai Cahaya Bulan indicate the direction of the wave

Figure 20: Soil samples were taken in Kampung Kor area

Figure 21: New ridges form in Pantai Seri Tujoh area indicate low energy environment where the microorganism can still live

Figure 22: Samples collected at the ridge environment

Figure above shows ridge depositional environment where the sample collected is fine and compacted silty sand. The presence of the Nibung root indicates that the location is nearby swale depositional environment, a shallow trough between ridges that run parallel to the shoreline.

Figure 23: Mud samples collected from Kg. Tok Sidi area.

Figure **Error! Reference source not found.** 23 shows the sample collected nearby paddy field is mud sample. The mud crack feature shown in **Error! Reference source not found.**b indicates that the area used to contain water. Mud or clay lithology found in the area represents the swampy depositional environment.

Data Analysis

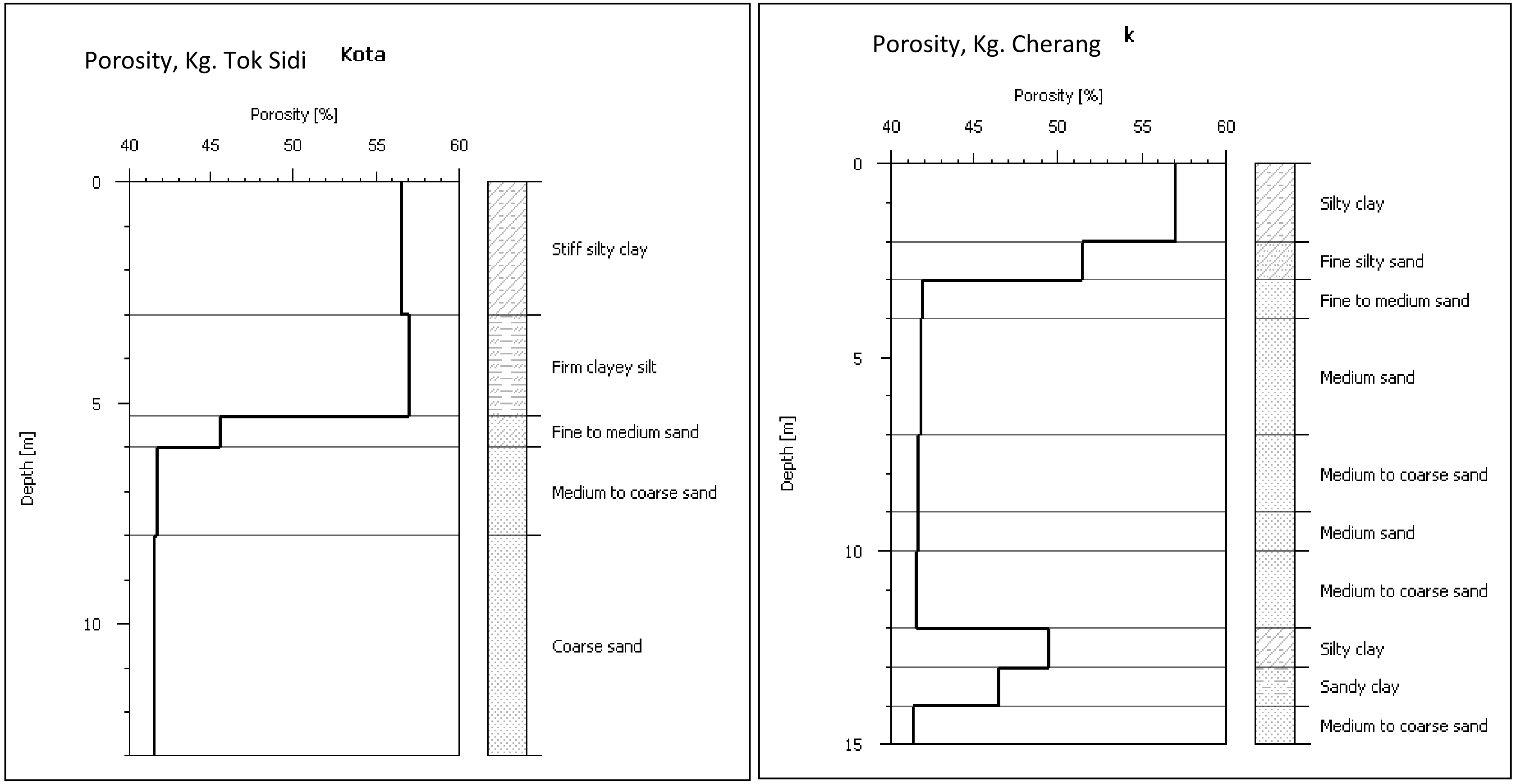
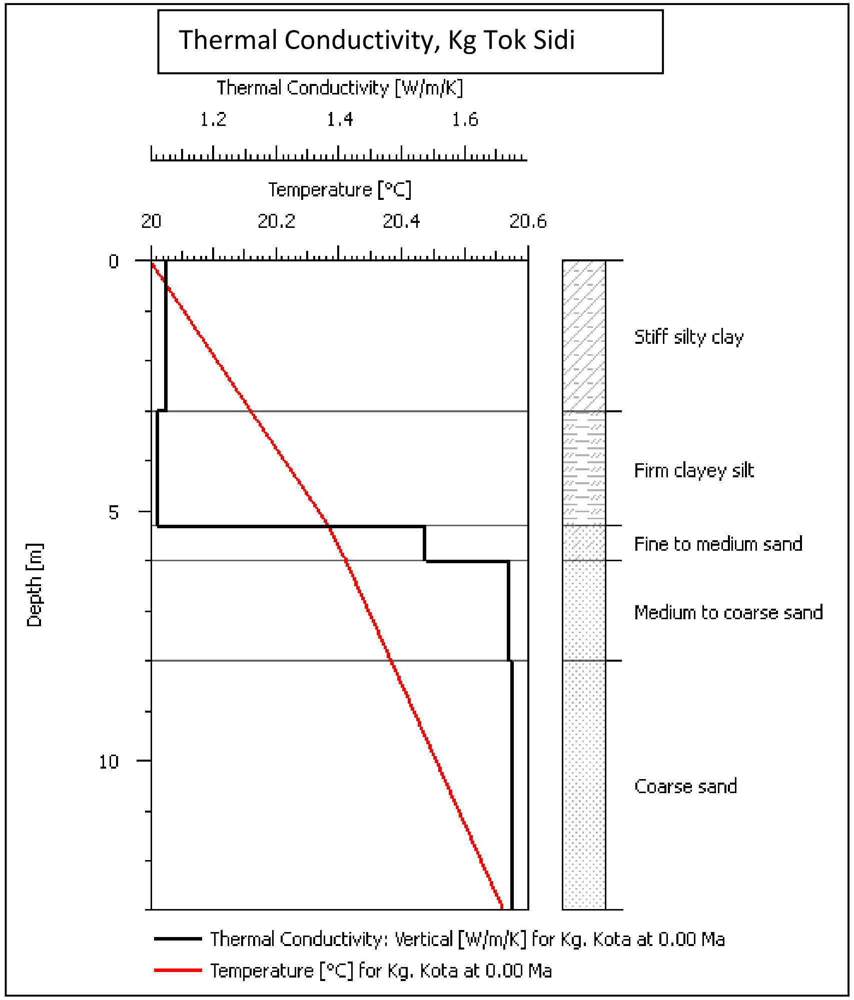


Figure 24: Porosity against depth data at Kg Tok Sidi and Kg Cherang showing porosity is decreasing as the depth increase



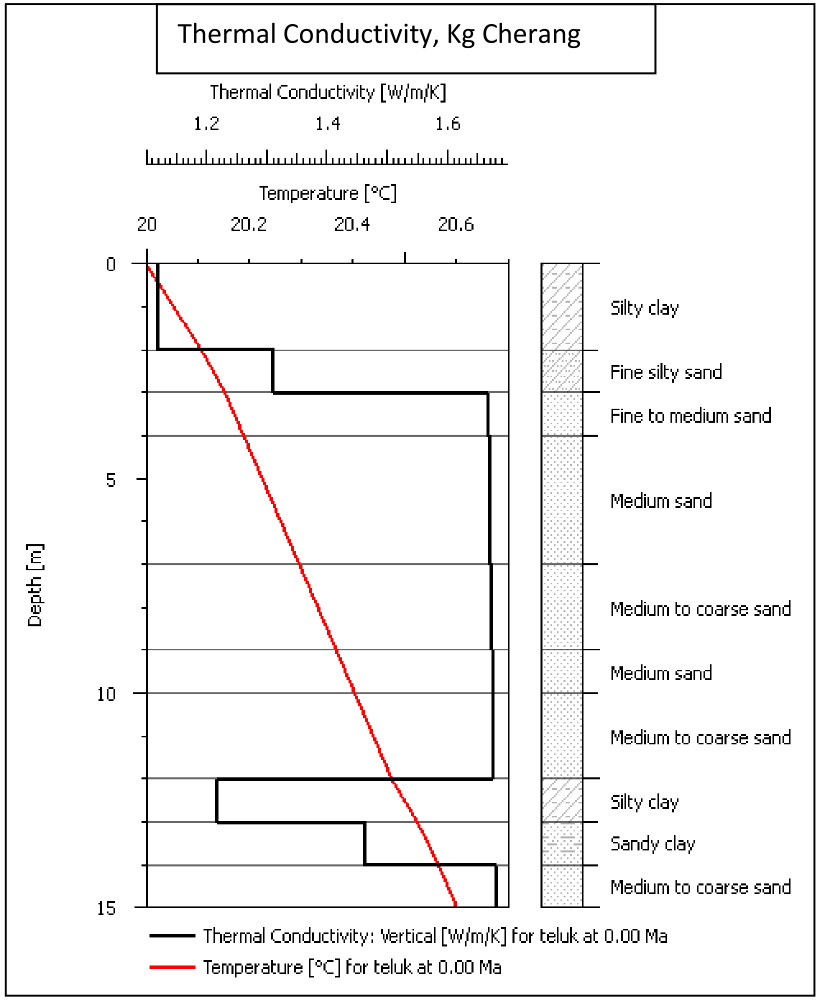


Figure 25: Thermal conductivity against depth data at Kg Tok Sidi and Kg Cherang showing porosity is decreasing as the depth increase

GRAIN SIZE DISTRIBUTION

RESULTS FROM SIEVING ANALYSIS

Table 3: Results of sieving analysis for Kampung Cherang

Sieve aperture (mm)	Weight retained (g)	Weight retained (%)	Cumulative weight retained (g)	Cumulative percent retained (%)	Grain size (phi)
2	2.17	1.09	2.17	1.09	-1
1	15.11	7.56	17.28	8.65	0
600µm	45.99	23.00	63.27	31.65	0.74
425µm	35.92	17.96	99.19	49.61	1.23
300µm	37.88	18.94	137.07	68.55	1.74
150µm	48.57	24.29	185.64	92.84	2.74
63µm	11.12	5.56	196.76	98.40	3.99
44µm	2.87	1.44	199.63	99.84	4.51

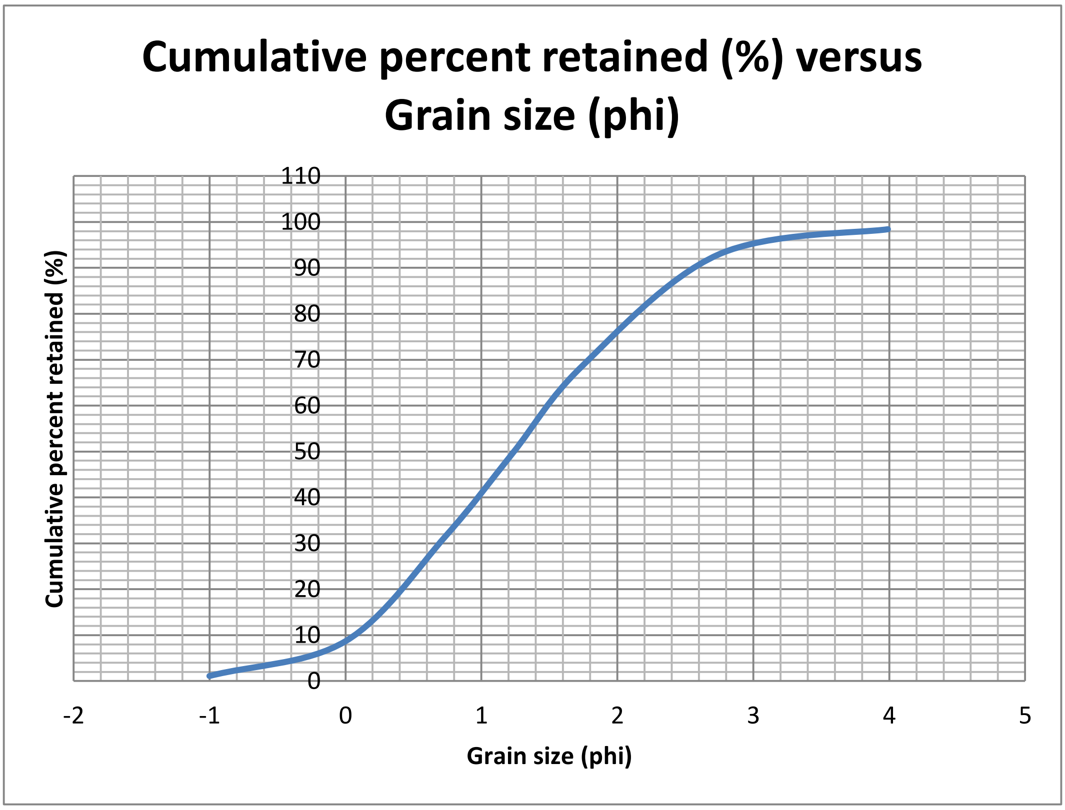


Figure 26: Graph of Analysis of Kampung Cherang data

Table 4: Results of sieving analysis for Kampung Tok Sidi

Sieve aperture (mm)	Weight retained (g)	Weight retained (%)	Cumulative weight retained (g)	Cumulative percent retained (%)	Grain size (phi)
2	84.37	42.19	84.37	42.19	-1
1	38.31	19.16	122.68	61.35	0
600µm	27.95	13.98	150.63	75.33	0.74
425µm	10.06	5.03	160.69	80.36	1.23
300µm	7.87	3.94	168.56	84.3	1.74
150µm	8.86	4.43	177.42	88.73	2.74
63µm	8.87	4.43	186.29	93.16	3.99
44µm	13.08	6.54	199.37	99.7	4.51

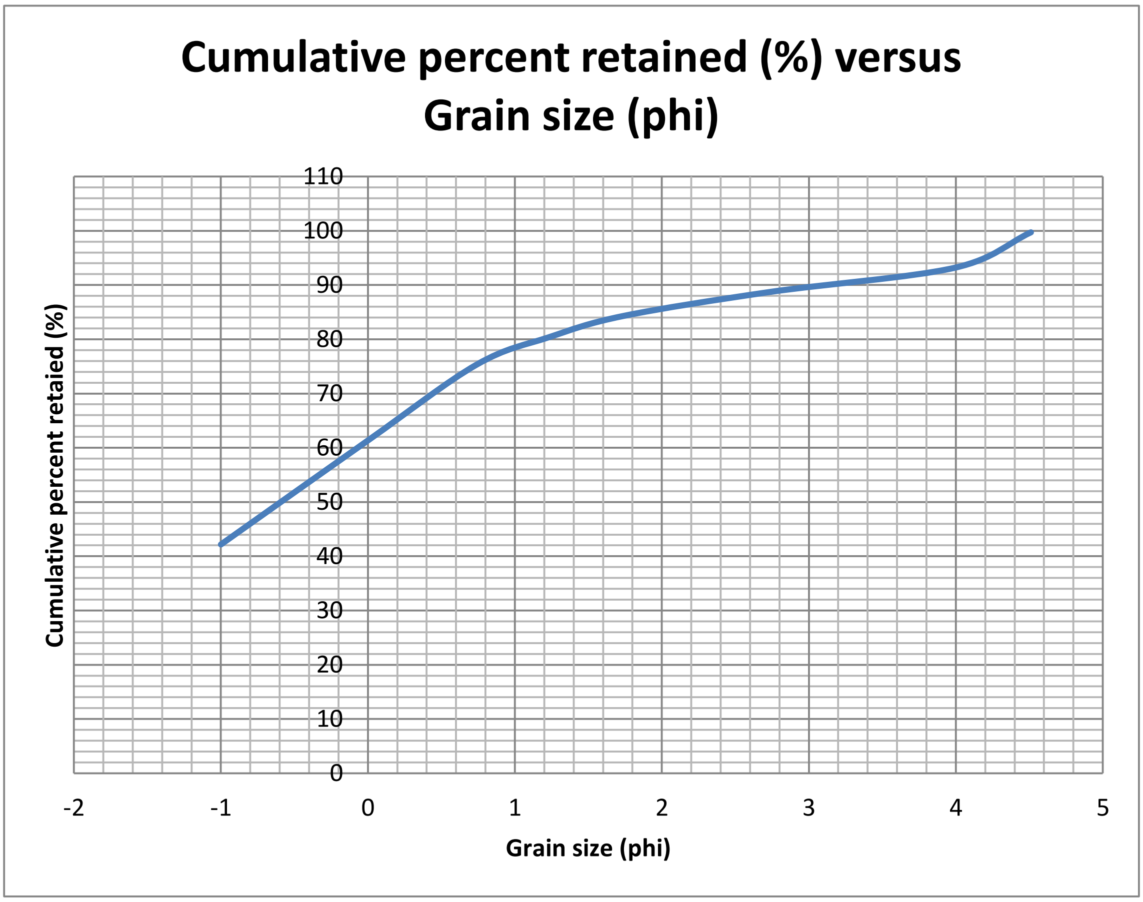


Figure 27: Graph of Analysis of Kampung Tok Sidi data

CHAPTER 5

CONCLUSION AND RECOMMENDATION

Thermal conductivity of rocks is clearly influenced by the porosity, temperature, thermal gradient, depth and lithologies. Behaviour of the reservoir in Central Malay Basin is controlled by the fault movement as can be seen from the temperature profile at Jerneh. It can be used at the interval of seal and reservoir. Compressions that cause Central Malay Basin to experience the basin inversion resulted in high thermal conductivity as the depth increases.

1. Thermal conductivity in Central Malay Basin ranges from 1.1- 3.0 W/m ^{o}K. Sandstone showing the highest thermal conductivity approaching 3.0 W/m ^{o}K due to the high degree of compaction at specified depth and low porosiry causing the fast movement of particle inside the formation.

2. Temperature increasing with depth in Jerneh showing concave upward trend which infer the intervals of seal and reservoir at the top of overpressure zone. The overpressure zone might indicate the presence of seal in the compression regime of Jerneh well.

3. Siltstone showing the very least value of thermal conductivity compared to sandstone and shale might be due to hugh porosity or void space which can be either air or water.

4. Thermal conductivity is higher in fluvio deltaic environment compared to marine or marine slope environment. This might be due to the higher compaction at where

high energy environment initiated. Low porosity in fluvial environment correspond to high thermal conductivity especially in sandstone.

RECOMMENDATIONS

1. A pilot study has been carried out by the author to investigate fluid flow history by analysis of reservoir petrography and fluid inclusion in diagenetic cements. Preliminary results (not reported in this thesis) lead me to recommend that a larger study can be conducted.

2. An additional of well could be added in analysis to produce a better and accurate value of thermal conductivity and its parameters.

3. Analysis on the pressure data with relation to thermal conductivity which relate to fluid movement of the reservoir could be attempted for further studies.

4. Analysis on different lithologies in relation with thermal conductivities could be investigated for further details about the unfolded history of Malay Basin

Throughout the completion of this project, I believe there will be some challenges and difficulties not only on the analysis part, but also on the data uploading part and writing the report. However, challenges are the common phase in learning process and therefore, I am highly hoping that despite the hurdles on completing this final year project, I can obtain successful outcomes and results as well as achieve the objectives.

I am also hoping that I would learn so much from the process of uploading all the well data and developing the geological logs. Mastering software would give so much advantage since especially as a final year student whom will be entering the industry and career world soon. By having such skills, one will not only can analyze the well, but could also help to evaluate the future performance of a well geologically.

Based on the readings and researches that I made, I came to conclude that thorough analysis needs to be carried out to develop more understanding regarding the sedimentary facies and depositional environment to characterise the reservoir as accurately as possible in order to calculate the reserve, and to determine the most effective way of recovering as much hydrocarbon as possible.

As a recommendation, I would like to suggest that the students could be given more time to complete final year project. This is on the logical that, more time given by the university, more studies and researches can be done by the students. A lot of reading would results in much bigger scope of a project and eventually will produces well-rounded and quality students. More time given also will provide the students with ample space to proceed with the experiments and field trips.

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